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ADVANCED USER INTERFACE CAPABILITIES FOR APPLICATION ON PORTABLE COMPUTERS

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This paper describes research conducted to examine the feasibility of using the fisheye concept to present complex diagrams and illustrations for use by Air Force maintenance personnel. Under the fisheye concept, the user is able to select for viewing those portions of graphics or subgraphics in which he is most interested. These items are presented in more detail while surrounding items of less interest are presented in less detail. The research demonstrated that the fisheye concept can be applied to present technical data for use in Air Force maintenance. However, it was noted that further study is needed to evaluate the relative effectiveness of the fisheye approach and other information presentation techniques to support maintenance activities.

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PREFACE

This paper describes a research effort conducted to examine the feasibility of using the fisheye concept to present automated technical manuals. The work was performed for the Air Force Armstrong Laboratory under contract F33615-87-D-0627 by the Industrial Engineering Department of Texas A&M University. Dr Deborah Mitta served as the principal investigator for Texas A&M. The Air Force technical monitor and principal investigator for this effort was Lt Cher E. Wynkoop, AL/HRGO.

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The efforts of many individuals within the Operational Logistics Branch have not gone unnoticed. I thank Mr. David Gunning for his continued interest in my research efforts; his comments, suggestions, and support have been greatly appreciated. I also thank Lieutenant Cher Wynkoop for her help in answering many of my questions concerning the logistical details of this contract. A special word of thanks goes to Mr. Robert C. Johnson (Branch Chief) and Dr. Donald L. Thomas (Senior Scientist) for their commitment to the research concepts presented in this report.

SUMMARY

The objective of this research was to examine the feasibility of using the fisheye concept to present complex diagrams and illustrations for use by Air Force maintenance personnel. Under the fisheye concept, the user is able to select for viewing those portions of graphics or subgraphics in which he is most interested. These items are presented in more detail while surrounding items of less interest are presented in less detail. The amount of detail and emphasis to be given each element of the graphic is based on weights developed using a series of algorithms. In this research the basic fisheye algorithms were adatpted and extended to accommodate the types of information required to support Air Force maintenance. The algorithms were then used to convert s1lample maintenance diagrams for fisheye presentation. The sample data was then used to develop a demonstration of the fisheye concept applied to maintenance data. A Macintosh computer and SuperCard software were used for the demonstration. The research demonstrated that the fisheye concept is applicable to maintenance.

I. Introduction

The Armstrong Laboratory is currently developing an integrated computer-based information system to aid in tasks associated with aircraft maintenance. This system is known as the Integrated Maintenance Information System (IMIS); its purpose is to provide a comprehensive computer-based system that consolidates existing aircraft maintenance information systems and databases. IMIS will provide maintenance technicians with a direct link to various maintenance information systems and databases such as supply data, historical databases, and automated technical orders. IMIS will provide diagnostic/troubleshooting recommendations, test procedures, appropriate graphics (e.g. locator diagrams and schematics). It will enable technicians to obtain fault data from built-in tests. Eventually IMIS will provide specialized data for aircraft battle damage assessment tasks, enable technicians to order parts from supply, and feature an automated training capability.

Operational Logistics Branch personnel (Logistics Research Division) recognize that human-computer interface issues associated with IMIS are important; one interest is in improving the quality of human-computer interaction. One human-computer interaction issue of primary concern is information presentation, in particular, presentation techniques that enhance the display of graphics-based aircraft maintenance information. With respect to information presentation, two interaction scenarios are of particular importance. These scenarios occur when (1) the size of the display medium restricts the amount of information that can be displayed and (2) information contains inappropriate levels of detail. Two traditional interface design approaches for data access in these scenarios are "scrolling" and "zoom lens" facilities. One problem with these traditional approaches, however, is that while scrolling and zooming actions enable access to detailed information, the views resulting from these actions provide no overall perspective.

One technique recently developed as a means of preserving global perspective while allowing information abbreviation or filtering is known as the fisheye lens viewing strategy (Furnas, 1982, 1986). This technique allows detailed information associated with a particular item of interest (focus point) to be presented; it also allows a viewer to gain perspective on the focus point with respect to the larger system of which it is a part.

The initial interest in examining the fisheye strategy was in establishing a mechanism for abbreviating information and filtering detail from maintenance data. The fisheye presentation strategy has recently been considered as a mechanism for filtering details associated with graphics-

based aircraft maintenance data. Additionally, several extensions of the original concept are reported (Mitta, 1989, 1990a, 1990b). The first extension allows the fisheye technique to be applied to any type of informational network (rather than solely to tree graphs); the second extension illustrates that fisheye views resulting from the selection of multiple focus points are possible.

Background

In order to build fisheye presentations from any type of network structure and incorporate multiple focus point selection, the following function is required. For a network consisting of the set of nodes $N = \{y_1, y_2, \ldots, y_{n-1}, y_n\}$, a presentation value for any node in N is determined according to the following function:

$$V_k = I_k - \sum_j D_{k,j}, \tag{1}$$

where

V_k = presentation value of node y_k

I_k = importance rating of node y_k

$D_{k,j}$ = minimum path distance between node y_k and focus point y_j .

Equation (1) represents a slight modification to Furnas' original degree of interest (DOI) function. The variable V_k is analogous to the degree of interest metric and remains a function of importance and distance; however, under the conditions of multiple focus point selection, the minimum path distance to each focus point must be considered (Mitta, 1989, 1990a, 1990b).

Note that the information abbreviation concepts addressed by this research are also addressed by the Aerospace Industries Association's recent initiative to simplify the content of graphics used in technical documentation. The Aerospace Industries Association (1989) contends that while the simplification of detailed, graphics-based information will result in a savings in creating, storing, and transmitting graphics, it will not deter from the utility of these graphics.

II. Objectives

The original fisheye concept revolves around the selection of objects referred to as focus points (network nodes). Based on the selected focus points and a given DOI (or V_k) threshold,

information abbreviation occurs. The next question one might ask is, "Suppose the selection of network arcs (in addition to the selection of network nodes) is desirable?" In other words the information of interest during an interaction scenario is a set of relationships between database elements. One might envision an IMIS troubleshooting scenario in which a technician suspects that a particular chip on a circuit board is causing a fault. In order to understand the extent of this chip's influence with respect to the remaining circuitry, the technician might wish to view information associated with an *is_connected_to* relationship and ultimately select this particular relationship.

Recall that aircraft maintenance data is represented as a relational database. In addition to providing a mechanism for the selection of information elements (network nodes), an accompanying fisheye interface would enable users to specify the links between information elements and in turn view respective fisheye presentations. Thus, focus relationship selection is another human-computer interaction issue that merits further examination.

The primary research objectives are to investigate (1) the concept of focus relationship selection and (2) the subsequent presentation of associated information. This type of information selection and presentation is suggested as a means of browsing graphics-based aircraft maintenance data. This report documents the development of the focus relationship selection concept and its implementation on a subset of IMIS maintenance data. Here, a component diagram representing Hydraulic System 1 of the F/A-18 is presented as a candidate data item.

An interface facilitating the selection of focus relationships and the subsequent browsing of maintenance information was designed. A prototype system incorporating an initial data subset (a simple circuit schematic and a portion of the Hydraulic System 1 component diagram) and the interface design was developed and discussed in detail in an earlier report (Mitta, 1990c).

III. Preliminary Research: Focus Relationship Selection

One issue that must be addressed if a relationship selection feature is to be incorporated into a fisheye interface is network connectivity. Given a connected graph G consisting of p nodes and q branches, let its branch set be defined as $\mathbf{B} = \{b_1, b_2, \ldots, b_q\}$. Since G is connected, it contains at least one spanning tree (Behzad, Chartrand, and Lesniak-Foster, 1979). By definition a spanning tree has $p-1$ branches; therefore, $q \geq p-1$. Let a subset of $\mathbf{B}$, $\mathbf{B}_s$, be defined such that

$\mathbf{B}_s = \{b_{s_1}, b_{s_2}, \ldots, b_{s_n}\}$, and $n \le q$. Since, by definition, a spanning tree must have $p - 1$ branches, if $n < p-1$, the resultant graph containing p nodes and branches $\mathbf{B}_s$ will be disconnected. For $n \ge p-1$, the graph formed by p nodes and branches $\mathbf{B}_s$ will be connected only under the condition that $\mathbf{B}_s$ contains a spanning tree. An examination of how a fisheye-like presentation strategy should be implemented under conditions of network disconnectedness was a topic for preliminary research. Note also that the subgraph formed by $\mathbf{B}_s$ may be disconnected.

In order to establish a set of initial conditions, consider a connected graph G′ with r' types of relationships. (A connected graph is one for which each node is linked to at least one other node via an arc.) The set of relationship types in G′ is defined as follows:

$$\mathbf{R} = \{r_1, r_2, \ldots, r_{r'}\}. \tag{2}$$

Let $\mathbf{R}_s$, a subset of R, be defined as follows:

$$\mathbf{R}_s = \{r_{s_1}, r_{s_2}, \ldots, r_{s_n}\}. \tag{3}$$

Here, $\mathbf{R}_s$ is the set containing n focus relationships. Focus relationship selection requires consideration of an important issue. Once a focus relationship set is identified, a connected subgraph resulting from this focus relationship is not guaranteed. Consider, for example, the tree graph of Figure 1. Suppose this network represents a system hierarchy, where the relationships between subsystems and sub-subsystems (indicated with heavy line widths) are of interest, that is, they are the focus relationships. The resultant subgraph is disconnected. The research issue is to implement a presentation strategy that is (1) based upon focus relationship selection and (2) analogous to the fisheye concept associated with focus point selection.

A functional expression for establishing the presentation value of a network relationship is required, where presentation value is determined with respect to a set of focus relationships. Consider a focus relationship r_j and the respective set of subgraphs consisting of r_j. Let the presentation value of a given relationship r_k be defined in terms of (1) its importance and (2) the distance between its respective subgraph and an r_j subgraph. The presentation value function is given as follows:

$$P_k = I_k - \sum_j \sum_i D_{k_i, r_j}, \tag{4}$$

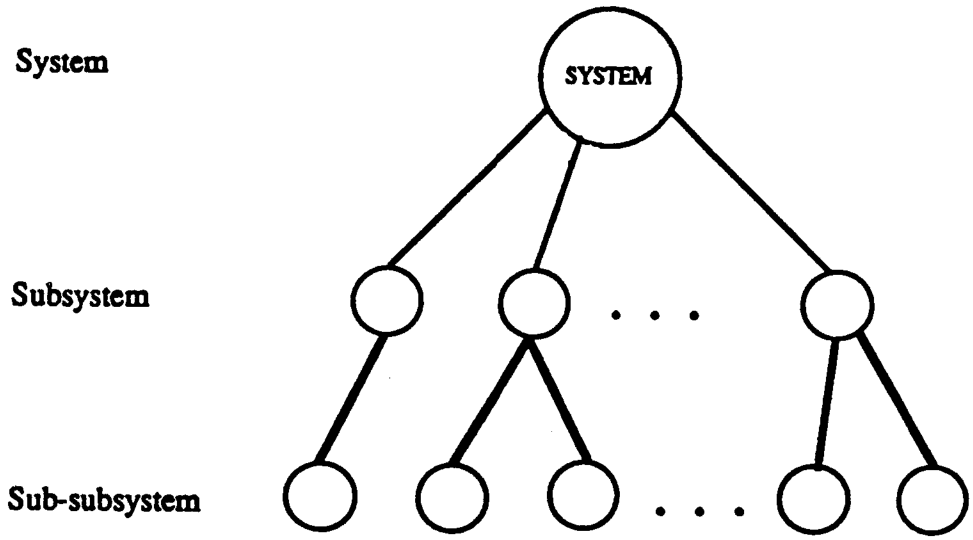

Figure 1. Tree Graph Representation of a System Hierarchy

where

P_k = presentation value of relationship r_k
I_k = importance of relationship r_k
D_{k_i,r_j} = minimum path distance between the ith connected subgraph consisting of r_k and a subgraph consisting of focus relaticnship r_j.

Thus, as indicated by Equation (4) the presentation value of r_k increases with importance and decreases with distances between r_k subgraphs and focus relationship subgraphs.

At this point a comment on the assignment of importance ratings to network relationships is appropriate. In the examples considered during this phase of the research, hierarchical tree graphs were of interest, and the parameter I_k was defined with respect to these types of acyclic network structures. Relationship importance, I_k, is weighted according to the number of node pairs spanned by relationship r_k at a given depth in the hierarchy, d (Mitta, 1990c). Consider a general tree graph (Figure 2). The hierarchical structure associated with this graph has m levels. The root node is assigned to level m, and nodes having the greatest path distance from the root are assigned to level one. For a hierarchy consisting of m levels, $1 \le d \le m-1$. For a relationship spanning hierarchical levels one and two, $d = 1$; a relationship spanning hierarchical levels two and three has a depth of $d = 2$. In general, then, given a relationship spanning levels m' and $m'+1$, $d = m'$. For a hierarchical tree graph of m levels, relationship importance I_k is defined as follows:

$$I_k = \sum_{d=1}^{m-1} n_{k_d} d, \tag{5}$$

where

I_k = importance of relationship r_k
d = depth of r_k
n_{k_d} = number of node pairs spanned by r_k at depth d.

Thus, the importance of a network relationship increases with its depth in the hierarchy and the number of node pairs it spans at a given depth. From Equation (5), Equation (4) can be rewritten as follows:

$$P_k = \sum_{d=1}^{m-1} n_{k_d} d - \sum_j \sum_i D_{k_i,r_j}. \tag{6}$$

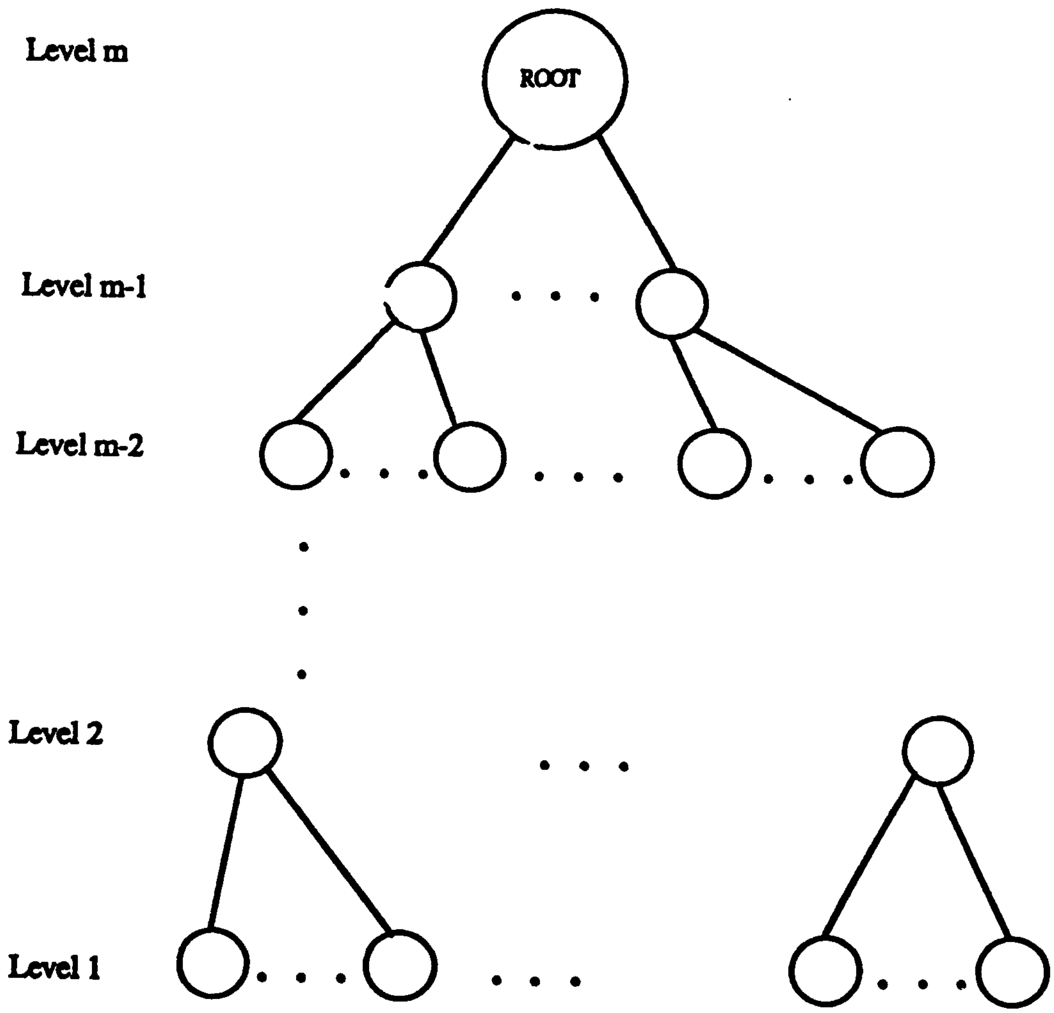

Figure 2. General Tree Graph

Note that in general, relationship importance must be determined heuristically. In other words for a general network with no underlying hierarchical structure, relationship importance must be defined in terms other than hierarchical depth. Through the setting of P_k thresholds, fisheye-like views with varying degrees of information content can be provided, thereby enabling the filtering or abbreviation of information. For a given threshold level t, the network relationships satisfying the condition $P_k \geq t$ have the greatest presentation value. As t is decreased, greater amounts of information are displayed.

Example: Application to Maintenance Data

Recall that simplifying graphics-based aircraft maintenance data is of interest. A component diagram of Hydraulic System 1 of the F/A-18 (Figure 3) was selected for application of the procedure described above, where the hierarchical structure underlying this system was of particular concern. An interface prototype, developed in *SuperCard™ 1.5* (Appleton and Poppitz, 1990), supports interaction scenarios for which relationships associated with Hydraulic System 1 are to be selected. Here, a preliminary description of a portion of the Hydraulic System 1 hierarchy is defined:

r_1: *unit*⟨fluid level indicator, hydraulic system 1⟩
unit⟨reservoir, hydraulic system 1⟩
unit⟨filter unit, hydraulic system 1⟩
unit⟨pressure transmitter, hydraulic system 1⟩

r_2: *component*⟨piston, reservoir⟩
component⟨valve, reservoir⟩
component⟨switches, reservoir⟩

r_3: *piston_type*⟨reservoir, piston⟩

r_4: *valve_type*⟨bleed, valve⟩
valve_type⟨case drain check, valve⟩
valve_type⟨overfill, valve⟩
valve_type⟨pilot, valve⟩
valve_type⟨shutoff, valve⟩

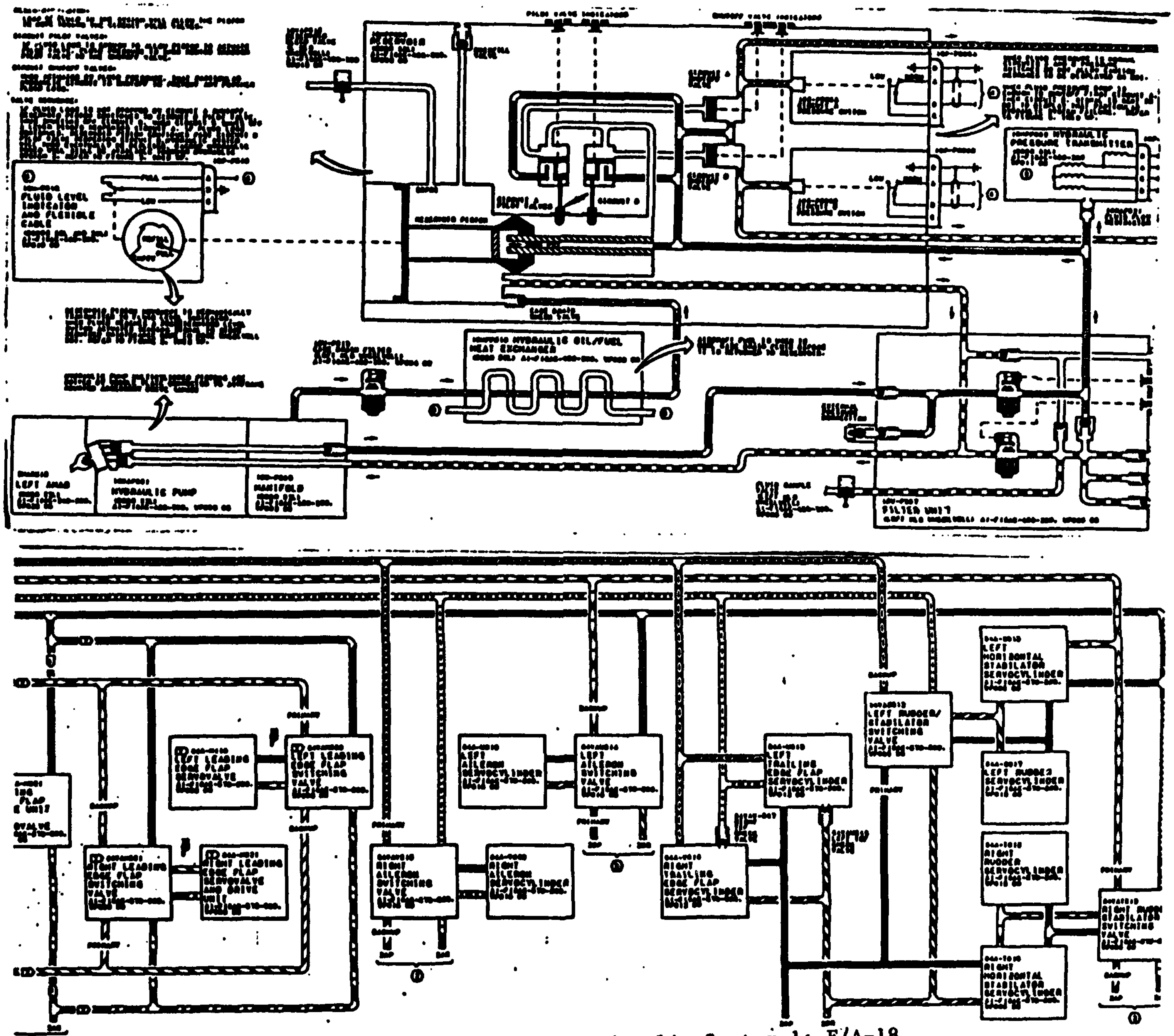

Figure 3. Hydraulic System 1: F/A-18

r_5: *switch_type*⟨pressure, switch⟩

r_6: *pilot_valve_circuit*⟨A, pilot valve⟩
pilot_valve_circuit⟨B, pilot valve⟩

r_7: *shutoff_valve_circuit*⟨A, shutoff valve⟩
shutoff_valve_circuit⟨B, shutoff valve⟩

r_8: *pressure_switch_circuit*⟨A, pressure switch⟩
pressure_switch_circuit⟨B, pressure switch⟩

r_9: *indicator*⟨A, pilot valve⟩
indicator⟨B, pilot valve⟩
indicator⟨A, shutoff valve⟩
indicator⟨B, shutoff valve⟩
indicator⟨A, pressure switch⟩
indicator⟨B, pressure switch⟩.

This hierarchical structure represents a graph with levels $m = 1, 2, \ldots, 6$ (Figure 4). Relationship r_1 (*unit*) spans levels five and six ($d = 5$), and r_2 (*component*) spans levels four and five ($d = 4$). Relationships r_3 (*piston_type*), r_4 (*valve_type*), and r_5 (*switch_type*) are located at a depth $d = 3$. Relationships r_6 (*pilot_valve_circuit*), r_7 (*shutoff_valve_circuit*), and r_8 (*pressure_switch_circuit*) are located at a depth of $d = 2$. Finally, relationship r_9 (*indicator*) spans levels one and two ($d = 1$).

An interface prototype was developed in SuperCard™ 1.5 (Appleton and Poppitz, 1990). This prototype supports interaction scenarios for which relationships associated with Hydraulic System 1 are to be selected. The menu bar (Figure 5) enables an end user to select from a set of relationships associated with the system hierarchy (**System Links**) and a set of relationships describing physical orientations of system components (**Operational Links**). Once a set of focus relationships has been selected, the **Data** menu allows the corresponding presentation of fisheye-like views.

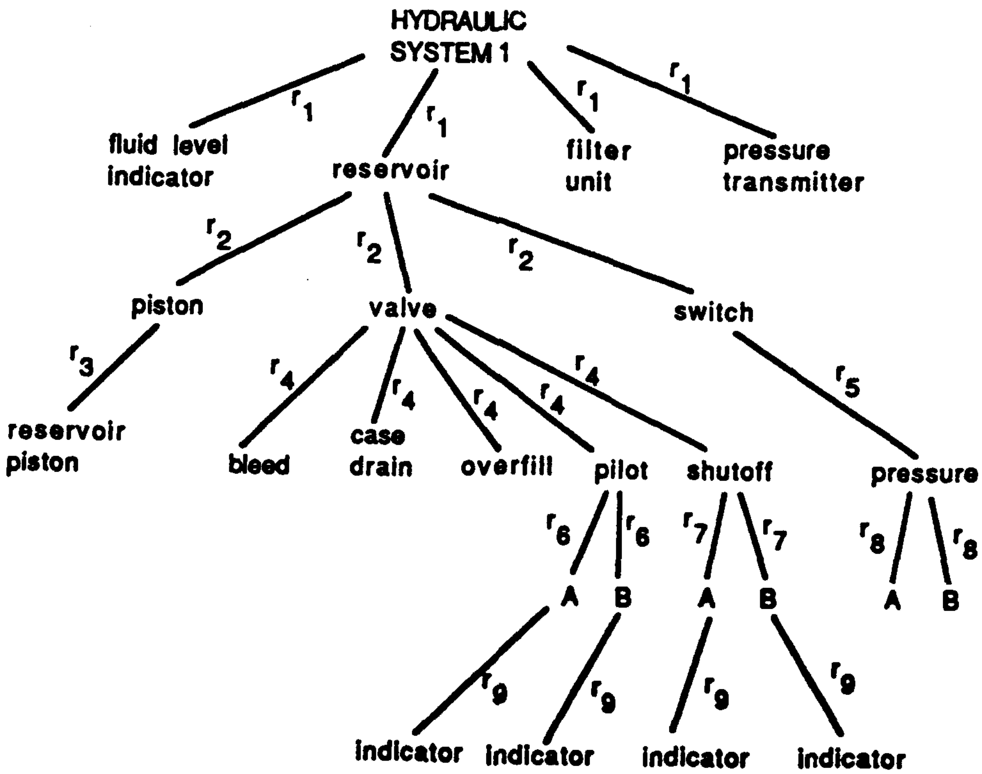

Figure 4. Hierarchical Structure of Hydraulic System

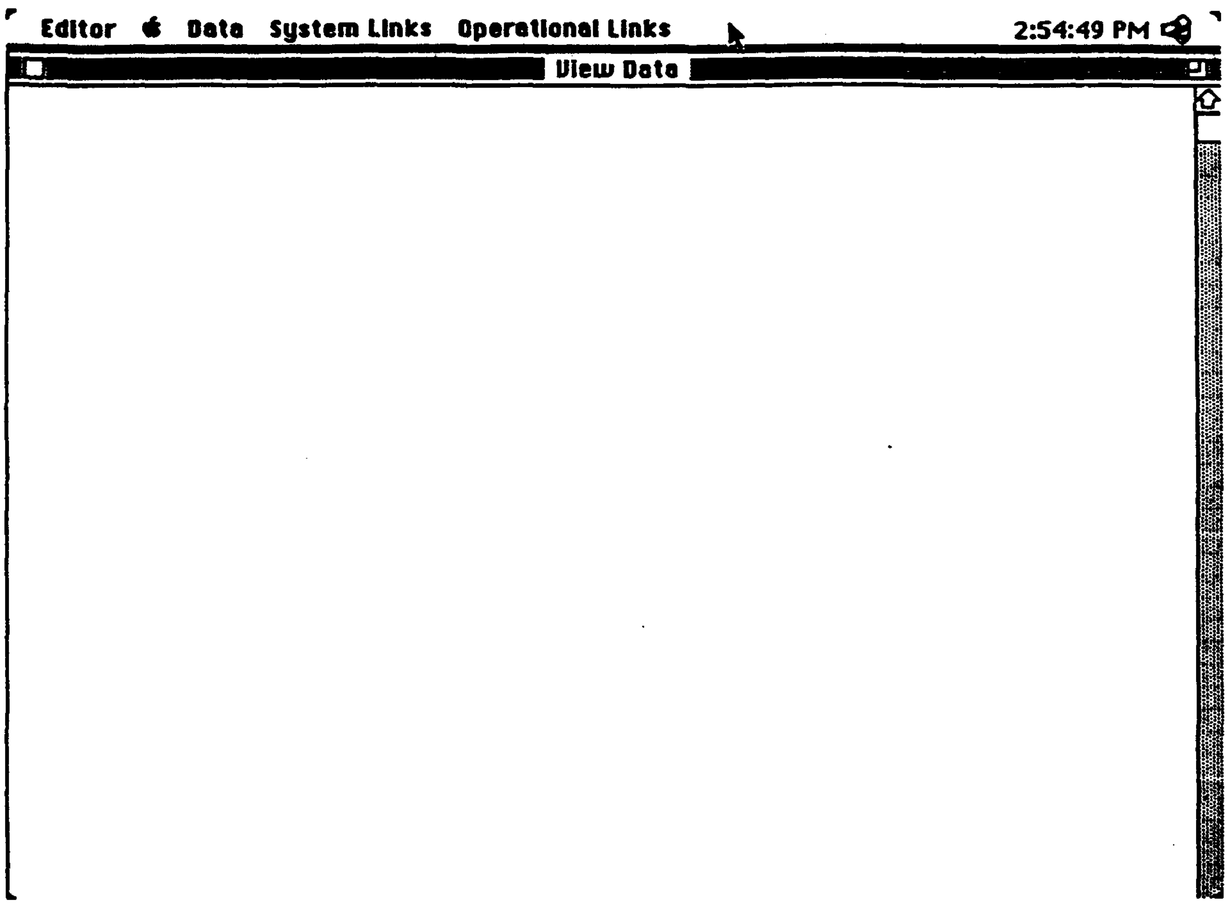

Figure 5. Interface Prototype Bar

The relationship set associated with the hierarchy of Hydraulic System 1 is defined as $\mathbf{R} = \{r_1, r_2, \ldots, r_9\}$. Suppose relationships r_1 (*unit*) and r_5 (*switch_type*) are selected as focus relationships: $\mathbf{R}_s = \{r_1, r_5\}$. Note that each focus relationship composes a single connected subgraph. The presentation value associated with each relationship is calculated according to Equation (6) such that $P_1 = 19$, $P_2 = 12$, $P_3 = 0$, $P_4 = 12$, $P_5 = 2$, $P_6 = -1$, $P_7 = -1$, $P_8 = 2$, and $P_9 = -24$.

Again, a brief explanation of several of the P_k calculations is perhaps appropriate. Consider focus relationship r_5 (*switch_type*). A single connected subgraph ($i = 1$) containing r_5 is located at a depth of $d = 3$. Additionally, r_5 spans one node pair at $d = 3$; therefore, $n_{5_3} = 1$, and $n_{5_1} = n_{5_2} = n_{5_4} = n_{5_5} = 0$. Finally, the minimum path distance between the r_5 subgraph and the r_1 subgraph is one, such that $D_{5_1, r_1} = 1$. Substitution into Equation (6) yields the following:

$$P_5 = [n_{5_1}(1) + n_{5_2}(2) + n_{5_3}(3) + n_{5_4}(4) + n_{5_5}(5)] - [D_{5_1, r_1} + D_{5_1, r_5}]$$
$$P_5 = [0(1) + 0(2) + 1(3) + 0(4) + 0(5)] - [1 + 0] = 2.$$

As a second example, consider relationship r_9 (*indicator*). Four connected *indicator* subgraphs ($i = 1, 2, 3, 4$) are located at a depth of $d = 1$. Each subgraph spans one node pair at $d = 1$, implying that $n_{9_1} = 4$, and $n_{9_2} = n_{9_3} = n_{9_4} = n_{9_5} = 0$. The minimum path distance between each r_9 subgraph and the r_1 subgraph is three ($D_{9_1, r_1} = D_{9_2, r_1} = D_{9_3, r_1} = D_{9_4, r_1} = 3$), and the minimum path distance between each r_9 subgraph and the r_5 subgraph is four ($D_{9_1, r_5} = D_{9_2, r_5} = D_{9_3, r_5} = D_{9_4, r_5} = 4$). Substitution into Equation (6) yields the following:

$$P_9 = [n_{9_1}(1) + n_{9_2}(2) + n_{9_3}(3) + n_{9_4}(4) + n_{9_5}(5)]$$
$$-[(D_{9_1, r_1} + D_{9_2, r_1} + D_{9_3, r_1} + D_{9_4, r_1}) + (D_{9_1, r_5} + D_{9_2, r_5} + D_{9_3, r_5} + D_{9_4, r_5})]$$
$$P_9 = [4(1) + 0(2) + 0(3) + 0(4) + 0(5)] - [4(3) + 4(4)] = -24.$$

Sample views of the hydraulic system were developed in SuperCard™ 1.5 (Appleton and Poppitz, 1990) and provided in Figures 6, 7, 8, 9, and 10. Figure 6 represents information associated exclusively with focus relationships r_1 and r_5:

r_1: *unit*$\langle$fluid level indicator, hydraulic system 1$\rangle$
unit$\langle$reservoir, hydraulic system 1$\rangle$
unit$\langle$filter unit, hydraulic system 1$\rangle$
unit$\langle$pressure transmitter, hydraulic system 1$\rangle$

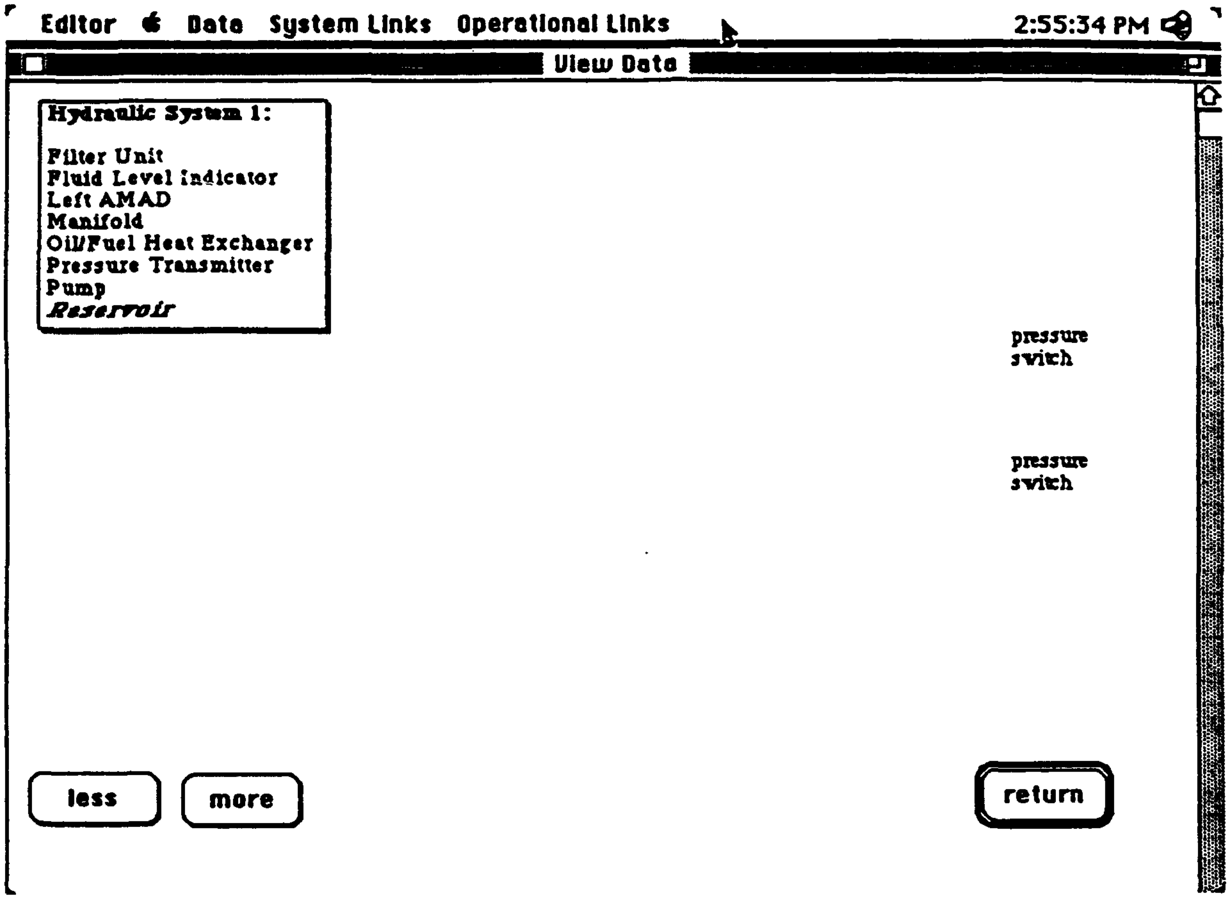

Figure 6. Information Associated with Focus Relationships r1 and r5.

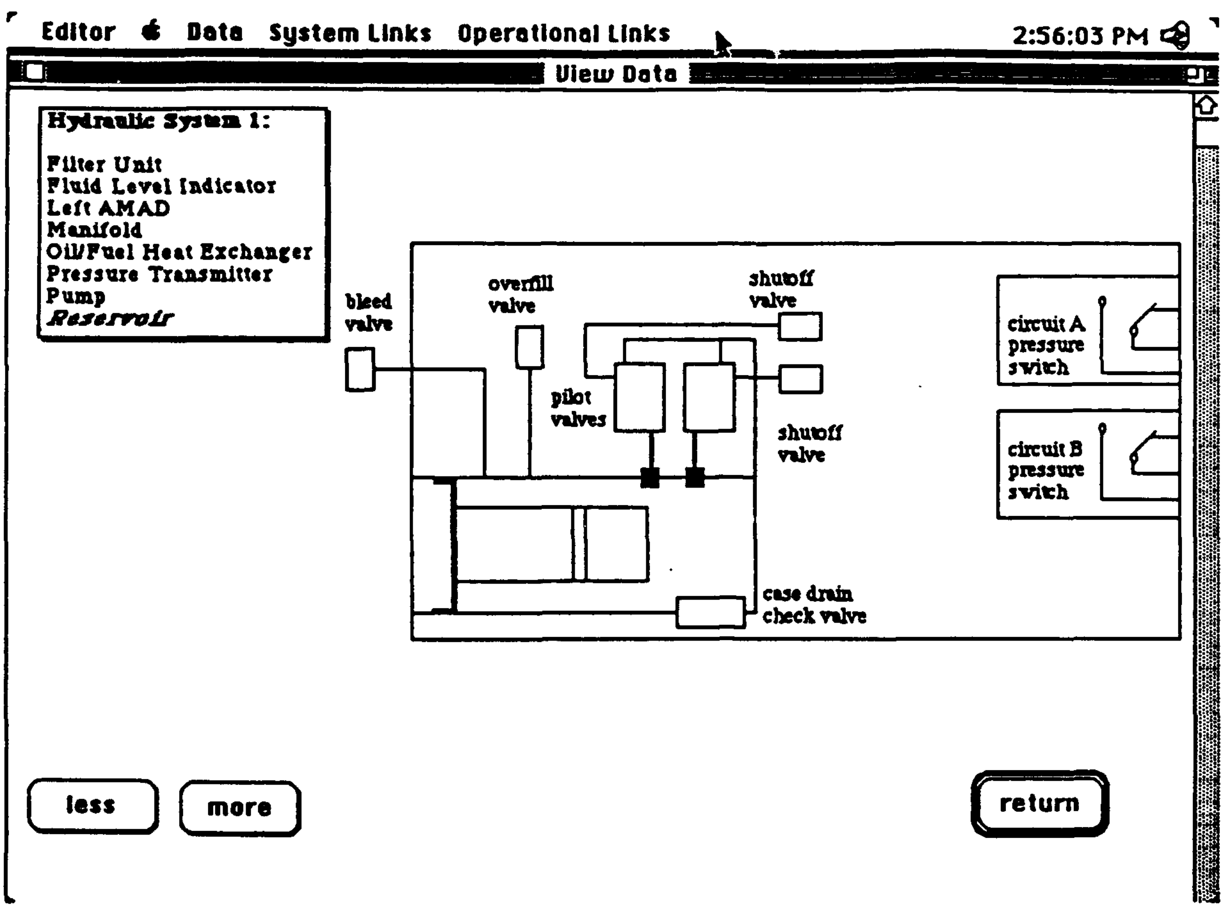

Figure 7. Information Associated with a Threshold $P_k \geq 2$

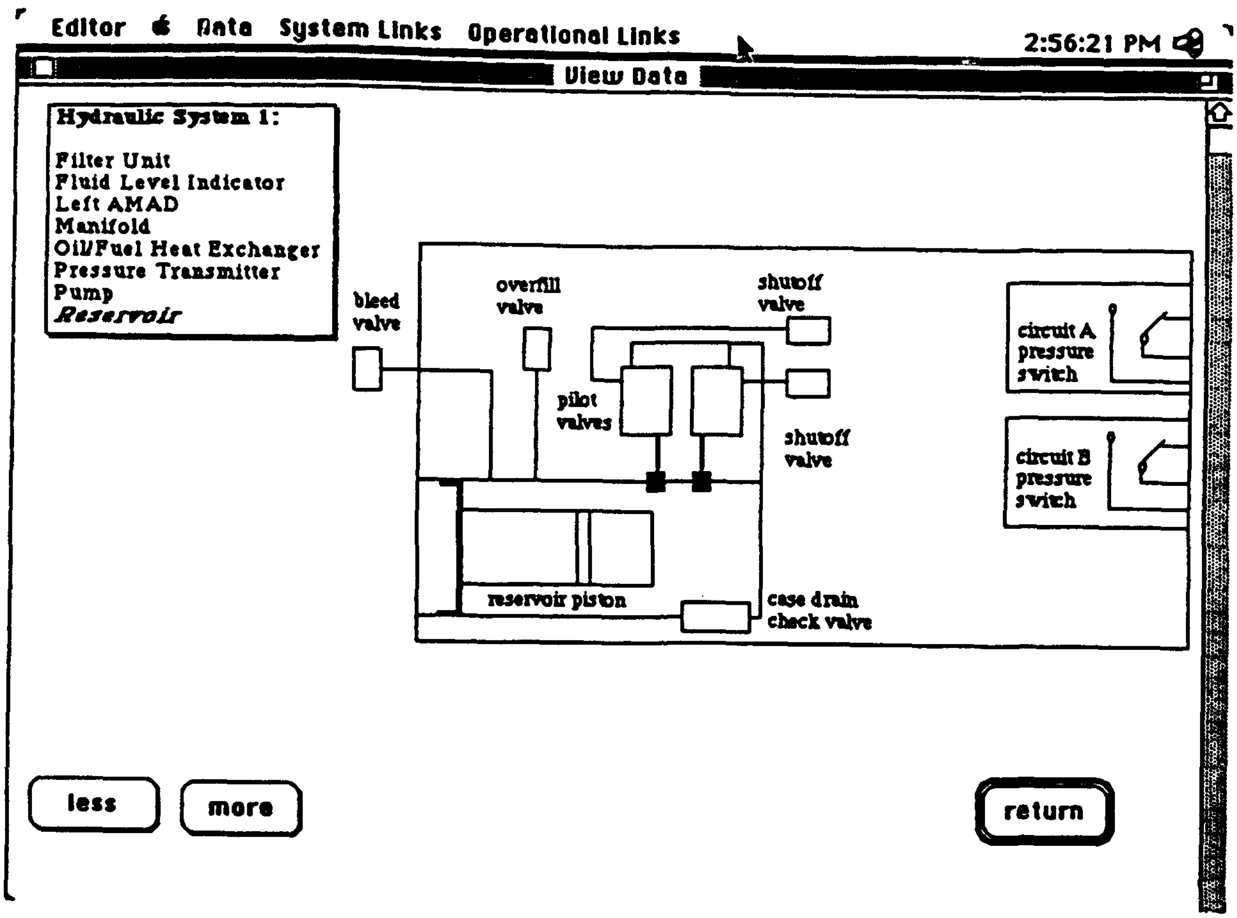

Figure 8. Information Associated with a Threshold $P_k \geq 0$

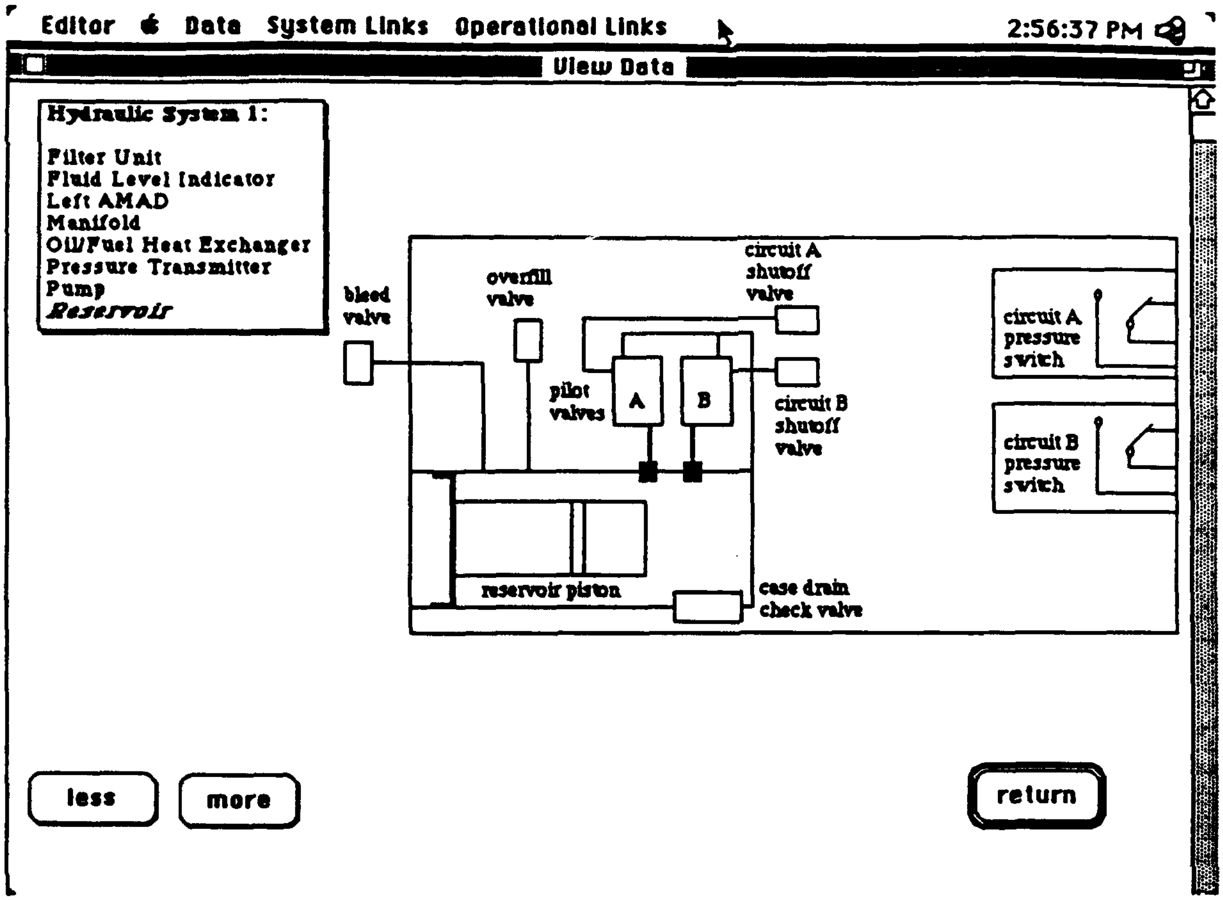

Figure 9. Information Associated with a Threshold $P_k \geq -1$

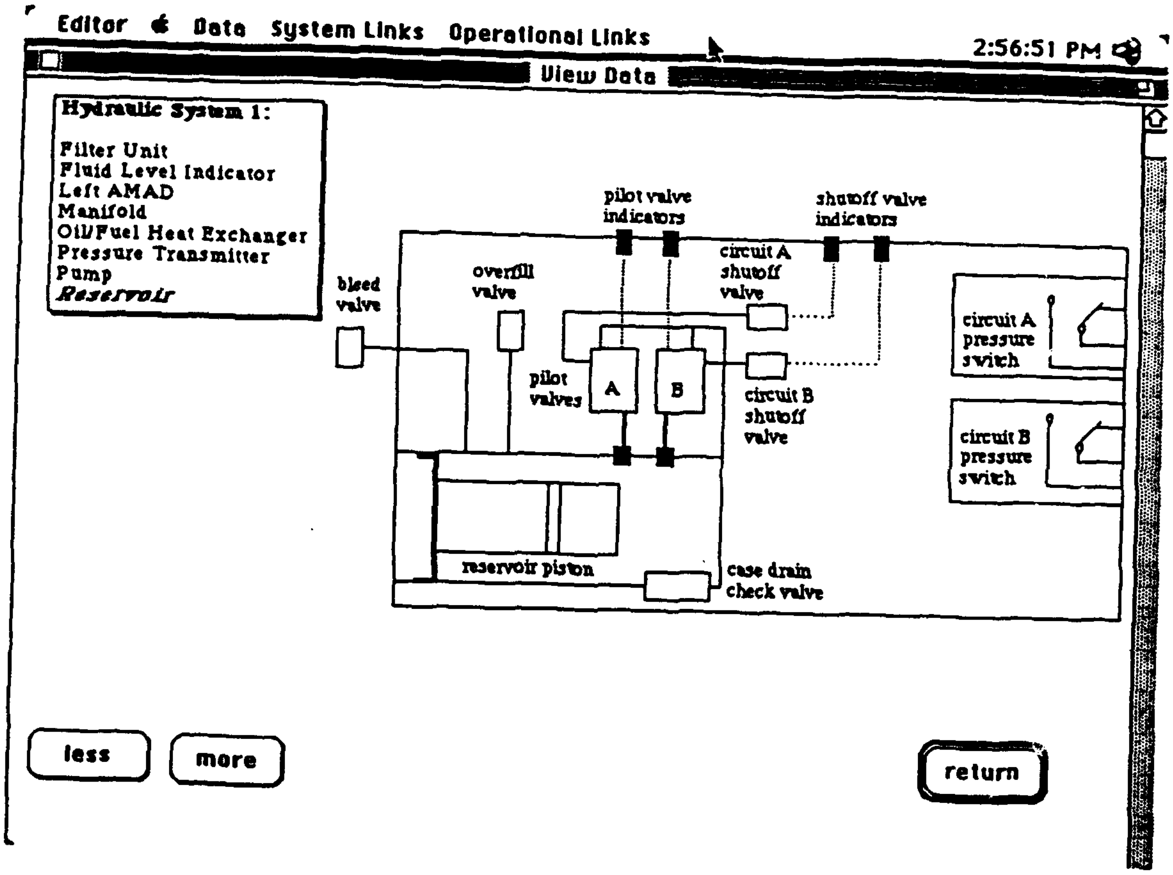

Figure 10. Information Associated with a Threshold $P_k \geq -24$

r_5 : *switch_type*$\langle$pressure, switch$\rangle$.

Figures 7 ($P_k \geq 2$), 8 ($P_k \geq 0$), 9 ($P_k \geq$ -1), and 10 ($P_k \geq$ -24) demonstrate the concept of information filtering: as P_k is decreased, additional graphics information is presented.

IV. Continuation of Research

Results of the preliminary research demonstrate a concept of focus relationship selection and the subsequent presentation of associated database information. The concept of focus relationship selection and the information presentation strategy described in the preceding section were suggested as a means of browsing graphics-based aircraft maintenance data, where a methodology for specifying information content at various browsing stages (established by P_k thresholds) was developed (Mitta, 1990c). This methodology is analogous to the original strategy attributed to Furnas (1982, 1986) for specifying information associated with a set of focus points.

In order to support future IMIS field tests, a complete specification of Hydraulic System 1 (F/A-18) relationships was required. The specification of system-subsystem (S/S) relationships has been extended to include the following: seven primary units (left airframe mounted accessory drive (AMAD), case drain filter, oil/fuel heat exchanger, reservoir, filter unit, pressure transmitter, flight control), components of the left AMAD (pump, manifold), components of the flight control unit (leading edge (LE) flap, aileron, trailing edge flap, rudder/stabilator), and additional subcomponents and parts. Figure 11 represents Hydraulic System 1 in terms of units, components, and subcomponents. Let a general S/S relationship be specified as follows:

S/S<*subsystem*, *system*>. (7)

Four S/S relationships associated with Hydraulic System 1 have been identified. These relationships are defined as

S/S<*unit*, *hydraulic system*> (8)

S/S<*component*, *unit*> (9)

S/S<*subcomponent*, *component*> (10)

S/S<*part*, *subcomponent*>. (11)

Through the notation of (7) the following hierarchical structure is specified: a unit is a subsystem of the hydraulic system, a component is a subsystem of a unit, a subcomponent is a subsystem of a component, and a part is a subsystem of a subcomponent. Thus, the relationships defined in (8) -

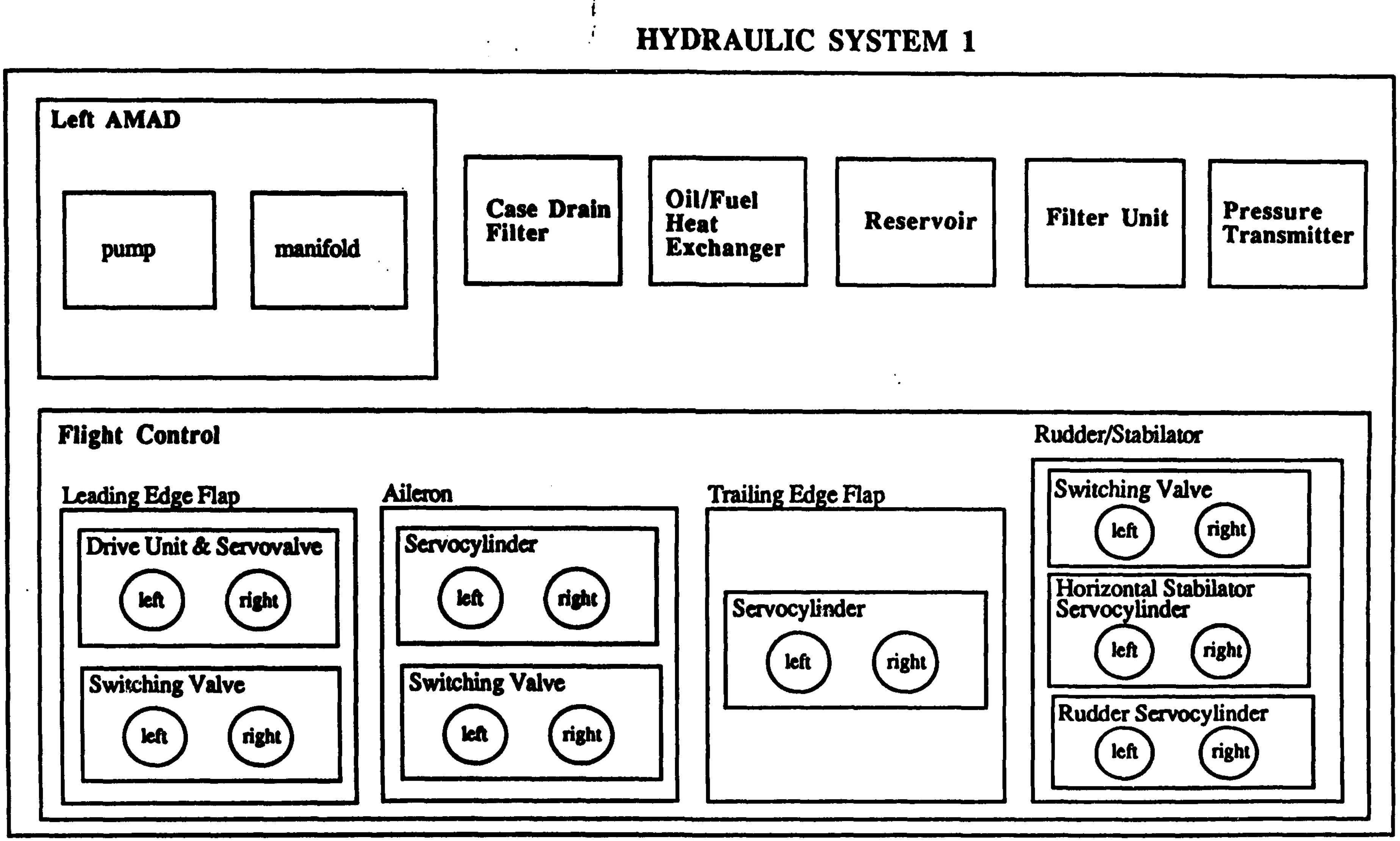

Figure 11. Block Diagram Representation of Hydraulic System 1

(11) establish a five-level system hierarchy, where the variables *hydraulic system*, *unit*, *component*, *subcomponent*, and *part* represent network objects (nodes). The set of S/S relationships defined for Hydraulic System 1 are given in Table 1.

The relationship specification also includes connectivity (I/O) relationships. Let a general I/O relationship be specified as follows:

$$\text{I/O}\langle output, input\rangle, \tag{12}$$

where the variable *output* refers to the node (system, unit, component, subcomponent, or part) from which the relationship originates, and the variable *input* refers to the node at which the relationship terminates. Thus, relationship (12) implies a directed network arc. The set of I/O relationships defined for Hydraulic System 1 are provided in Table 2.

During discussions with Operational Logistics Branch personnel, a modification to the initial methodology (developed for the presentation of fisheye-like views based upon selection of network relationships in Mitta, 1990c) was suggested. Two types of relationships (S/S and I/O) were identified as critical. The modification centered around users' abilities to select system-subsystem and/or connectivity relationships, in addition to focus points, and subsequently view a simplified graphic. In other words users should have the capability to select a set of focus points, as well as S/S and/or I/O relationships. Once focus points and desired relationship type(s) are identified, a simplified graphic should be available for electronic presentation, where the content of the simplified graphic is specified according to the presentation value V_k assigned to each network node y_k.

V. Modified Methodology

Equation (1) is used to calculate presentation values for each system object (network node). Note that node importance I_k is defined as the hierarchical path distance (not necessarily the minimum path distance) from the root node. Consider a set of network nodes $N = \{n_{f_1}, n_{f_2}, \ldots, n_{f_n}, n_1, n_2, \ldots, n_m\}$, where nodes $n_{f_1}, n_{f_2}, \ldots, n_{f_n}$ are defined as focus points. Thus, the network contains $n + m$ nodes. Based upon the given set of focus points, a presentation value for each node is calculated according to the following equations:

$$V_{n_{f_k}} = I_{n_{f_k}} - \sum_{i=1}^{n} D_{n_{f_k}, n_{f_i}} \qquad (1 \leq k \leq n) \tag{13}$$

TABLE 1

Hierarchical Structure of Hydraulic System 1

S/S Relationships

- S/S<left AMAD, hydraulic system 1>
  - S/S<pump, left AMAD>
  - S/S<manifold, left AMAD>
- S/S<case drain filter, hydraulic system 1>
- S/S<oil/fuel heat exchanger, hydraulic system 1>
- S/S<reservoir, hydraulic system 1>
- S/S<filter unit, hydraulic system 1>
- S/S<pressure transmitter, hydraulic system 1>
- S/S<flight control, hydraulic system 1>
  - S/S<leading edge (LE) flap, flight control>
    - S/S<LE flap drive unit & servovalve, LE flap>
      - S/S<left LE flap drive unit & servovalve, LE flap drive unit & servovalve>
      - S/S<right LE flap drive unit & servovalve, LE flap drive unit & servovalve>
    - S/S<LE flap switching valve, LE flap>
      - S/S<left LE flap switching valve, LE flap switching valve>
      - S/S<right LE flap switching valve, LE flap switching valve>
  - S/S<aileron, flight control>
    - S/S<aileron servocylinder, aileron>
      - S/S<left aileron servocylinder, aileron servocylinder>
      - S/S<right aileron servocylinder, aileron servocylinder>
    - S/S<aileron switching valve, aileron>
      - S/S<left aileron switching valve, aileron switching valve>
      - S/S<right aileron switching valve, aileron switching valve>
  - S/S<trailing edge (TE) flap, flight control>
    - S/S<TE flap servocylinder, TE flap>
      - S/S<left TE flap servocylinder, TE flap servocylinder>
      - S/S<right TE flap servocylinder, TE flap servocylinder>
  - S/S<rudder/stabilator, flight control>
    - S/S<rudder/stabilator switching valve, rudder/stabilator>
      - S/S<left rudder/stabilator switching valve, rudder/stabilator switching valve>
      - S/S<right rudder/stabilator switching valve, rudder/stabilator switching valve>
    - S/S<horizontal stabilator servocylinder, rudder/stabilator>
      - S/S<left horizontal stabilator servocylinder, horizontal stabilator servocylinder>
      - S/S<right horizontal stabilator servocylinder, horizontal stabilator servocylinder>
    - S/S<rudder servocylinder, rudder/stabilator>
      - S/S<left rudder servocylinder, rudder servocylinder>
      - S/S<right rudder servocylinder, rudder servocylinder>

TABLE 2

Connectivity Relationships of Hydraulic System 1

I/O Relationships

I/O<left AMAD, case drain filter>
I/O<case drain filter, oil/fuel heat exchanger>
I/O<oil/fuel heat exchanger, reservoir>
I/O<reservoir, filter unit>
I/O<filter unit, pressure transmitter>
I/O<left AMAD, filter unit>
I/O<filter unit, left AMAD>
I/O<reservoir, pressure transmitter>
I/O<pressure transmitter, reservoir>
I/O<reservoir, LE flap drive unit & servovalve>
I/O<LE flap drive unit & servovalve, filter unit>
I/O<left LE flap drive unit & servovalve, left LE flap switching valve>
I/O<left LE flap switching valve, left LE flap drive unit & servovalve>
I/O<left aileron switching valve, left aileron servocylinder>
I/O<left aileron servocylinder, left aileron switching valve>
I/O<right aileron switching valve, right aileron servocylinder>
I/O<right aileron servocylinder, right aileron switching valve>
I/O<right rudder/stabilator switching valve, right rudder servocylinder>
I/O<right rudder servocylinder, right rudder/stabilator switching valve>
I/O<right rudder/stabilator switching valve, right horizontal stabilator servocylinder>
I/O<right horizontal stabilator servocylinder, right rudder/stabilator switching valve>
I/O<reservoir, left LE flap switching valve>
I/O<left LE flap switching valve, filter unit>
I/O<reservoir, right LE flap switching valve>
I/O<right LE flap switching valve, filter unit>
I/O<reservoir, left aileron switching valve>
I/O<left aileron switching valve, filter unit>
I/O<reservoir, right aileron switching valve>
I/O<right aileron switching valve, filter unit>
I/O<reservoir, left TE flap servocylinder>
I/O<left TE flap servocylinder, filter unit>
I/O<reservoir, right TE flap servocylinder>
I/O<right TE flap servocylinder, filter unit>

TABLE 2 (cont'd)

Connectivity Relationships of Hydraulic System 1

I/O Relationships

I/O<reservoir, left rudder/stabilator switching valve>
I/O<left rudder/stabilator switching valve, filter unit>
I/O<reservoir, right rudder/stabilator switching valve>
I/O<right rudder/stabilator switching valve, filter unit>
I/O<reservoir, left horizontal stabilator servocylinder>
I/O<left horizontal stabilator servocylinder, filter unit>

$$V_{n_j} = I_{n_j} - \sum_{i=1}^{n} D_{n_j,n_{f_i}} \qquad (1 \le j \le m). \tag{14}$$

Here, $V_{n_{f_k}}$ is the presentation value assigned to focus point n_{f_k}; $I_{n_{f_k}}$ is the hierarchical path distance from the root node to n_{f_k}; and $D_{n_{f_k},n_{f_i}}$ is the minimum path distance between focus points n_{f_k} and n_{f_i}. Likewise, V_{n_j} is the presentation value assigned to node n_j; I_{n_j} is the hierarchical path distance from the root node to n_j; and $D_{n_j,n_{f_i}}$ is the minimum path distance between n_j and focus point n_{f_i}.

The simplified graphic contains information associated with all focus point nodes, in addition to a subset of nodes from $n_1, n_2, \ldots, n_m$ for which $V_{n_j} \ge \min\{V_{n_{f_1}}, V_{n_{f_2}}, \ldots, V_{n_{f_k}}\}$. Let the nodes $n_1, n_2, \ldots, n_m$ for which $V_{n_j} \ge \min\{V_{n_{f_1}}, V_{n_{f_2}}, \ldots, V_{n_{f_k}}\}$ be defined as N_s (a subset of $n_1, n_2, \ldots, n_m$):

$$N_s = \{n'_1, n'_2, \ldots, n'_{m-p}\}, \tag{15}$$

where $0 \le p < m$. The simplified graphic also includes selected relationship types (S/S and/or I/O) connecting all nodes within/between N_s and the focus points $n_{f_1}, n_{f_2}, \ldots, n_{f_n}$. This methodology is demonstrated in the following example.

Example of Modified Methodology: Hydraulic System 1

Consider Hydraulic System 1 and its corresponding block diagram provided in Figure 11. Suppose three focus points are selected: filter unit (FU), LE flap, and left aileron switching valve (ASV_L). Based upon the set of S/S and I/O relationships provided in Tables 1 and 2, respectively, presentation values for each system node (object) can be calculated according to Equations (13) and (14). Presentation values for the three focus points are as follows: $V_{FU} = -5$, $V_{LE\ flap} = -8$, and $V_{ASV_L} = -9$. Thus, the resultant simplified graphic will contain information associated with the FU, LE flap, and ASV_L, in addition to information associated with those nodes for which presentation values are greater than or equal to -9. Suppose that both S/S and I/O relationships are of interest in this particular interaction scenario. The simplified graphic will also represent any S/S and I/O connections that exist within and between the focus points and nodes with presentation values of at least -9.

According to the methodology described previously, 16 system nodes should be included in the simplified graphic. The objects appearing in boldface type are the focus points.

- hydraulic system 1
- left AMAD
- case drain filter
- oil/fuel heat exchanger
- reservoir
- **filter unit**
- pressure transmitter
- flight control
- **LE flap**
- aileron
- LE flap drive unit & servovalve
- LE flap switching valve
- aileron switching valve
- left LE flap switching valve
- right LE flap switching valve
- **ASV_L**.

Prototype Views

A system prototype was developed in SuperCard™ 1.5 (Appleton and Poppitz, 1990). This prototype supports interaction scenarios for which Hydraulic System 1 objects (focus points) and S/S, I/O, or S/S and I/O relationships are selected. The prototype subsequently displays the simplified graphics associated with these selections. The simplified graphics contain information associated with all focus point objects and those system objects for which $V_{a_j} \geq \min\{V_{a_1}, V_{a_2}, \ldots, V_{a_k}\}$, in addition to the selected relationship information (S/S, I/O, or the combination of S/S and I/O).

Figure 12 depicts the main menu of the prototype system. The **Data** menu (with menu items ***Procedures***, ***Graphics***, and ***Quit***) enables technicians to view text-based (***Procedures***) or graphics-based (*Graphics*) maintenance data or terminate the maintenance activity (*Quit*). Note that this research effort focused on the simplification and ultimate presentation of graphics-based data; therefore, the prototype supports simplified views based on selection of the *Graphics* and *Quit* items only. The **Selections** menu contains four items: *Focus Points*, *System/Subsystem & Input/Output*, *System/Subsystem*, and *Input/Output*. Menu item *Focus Points* enables user selection of focus point objects. Selection of menu items *System/Subsystem & Input/Output*,

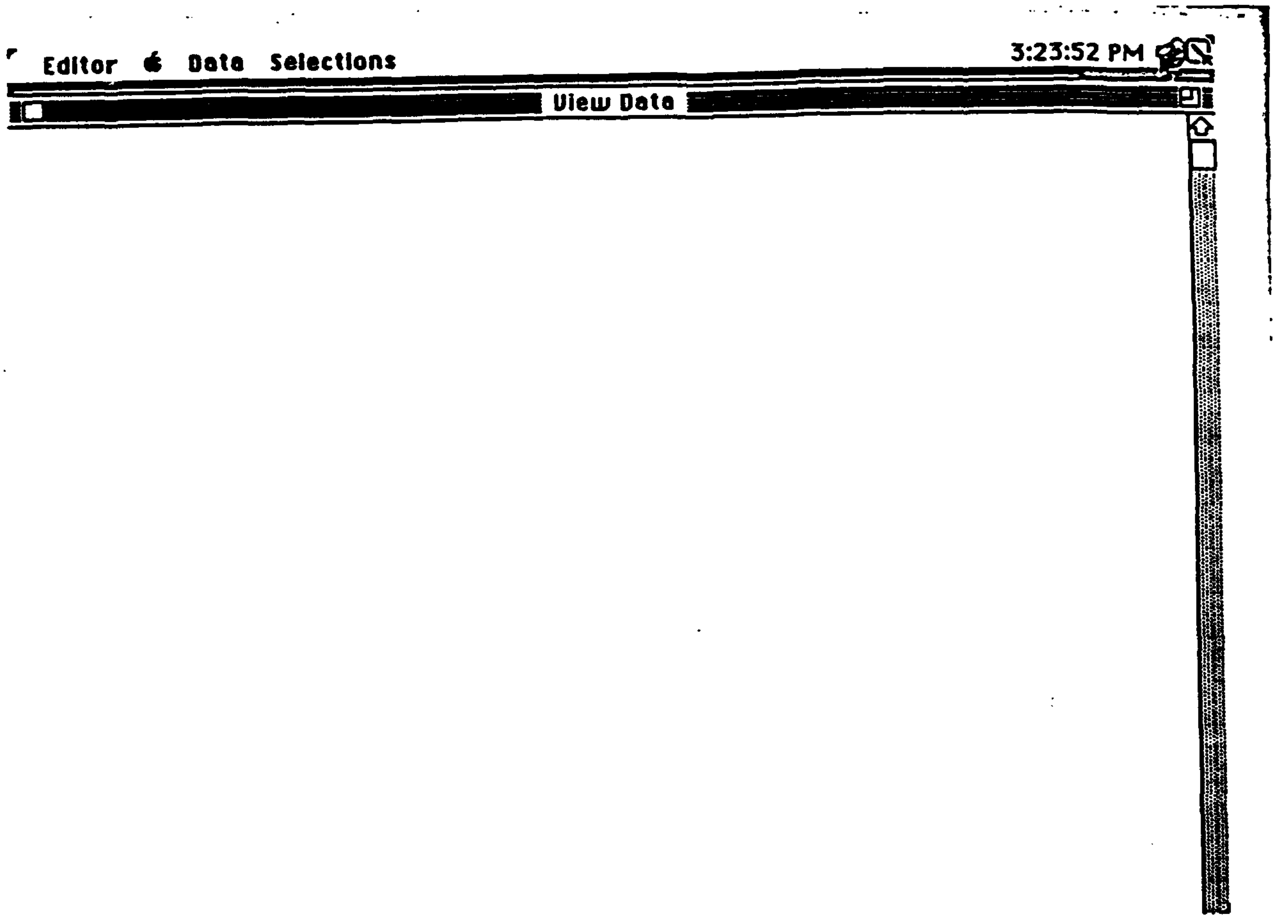

Figure 12. Main Menu Bar for Prototype System

System/Subsystem, or *Input/Output* enables users to view a simplified graphic displaying information associated with system/subsystem and input/output, system/subsystem, or input/output relationships, respectively.

Figure 13 represents the result of a user's selection of the menu item *Graphics*. The user may choose to view from a set of diagrams or circuit schematics. In this figure the user wishes to view a diagram of Hydraulic System 1. Once the *OK* button has been selected, the user is presented the block diagram representation of Hydraulic System 1 (Figure 14). The result of the user's selection of the menu item *Focus Points* is shown in Figure 15. In this figure selection of two of the three focus points considered in this example (filter unit and leading edge flap) is shown. Note that selection of the third focus point (left aileron switching valve) is not shown in this portion of the focus point selection window.

When the menu item *Input/Output* is selected, the user is presented a simplified view of Hydraulic System 1 (Figure 16). This view is based upon focus points FU, LE flap, and ASV_L. The remaining 13 system objects listed above (for which $V_k \geq -9$) are included in the view. As a result of the selection of menu item *Input/Output*, all input/output relationships connecting these 16 nodes are shown. These relationships are represented as directed arcs. In Figure 16, for example, a unidirectional connection exists from the case drain filter to the oil/fuel heat exchanger, while a bidirectional connection between the reservoir and the pressure transmitter also exists. Figure 17 shows the simplified graphic resulting from selection of menu item *System/Subsystem*. Note from the figure that these relationships are implied; they are not implicitly represented, as are the I/O relationships of Figure 16. Finally, Figure 18 shows the simplified graphic resulting from selection of menu item *System/Subsystem & Input/Output*. Here, information from Figures 16 and 17 is combined.

Figure 15 represents one method by which users select focus points. This method requires users to select focus points from a list of system objects (displayed in a separate focus point selection window). Suppose users are required to select focus points directly from the graphics data in which they are interested. Consider again the block diagram of Hydraulic System 1 (Figure 14), and suppose users select focus points simply by clicking on any of the objects represented in the diagram. A second prototype enabling this more direct method of focus point selection was also developed in SuperCard™ 1.5 (Appleton and Poppitz, 1990). Figure 19 shows the result of a user's selection of the following seven focus points: left AMAD, case drain filter, reservoir,

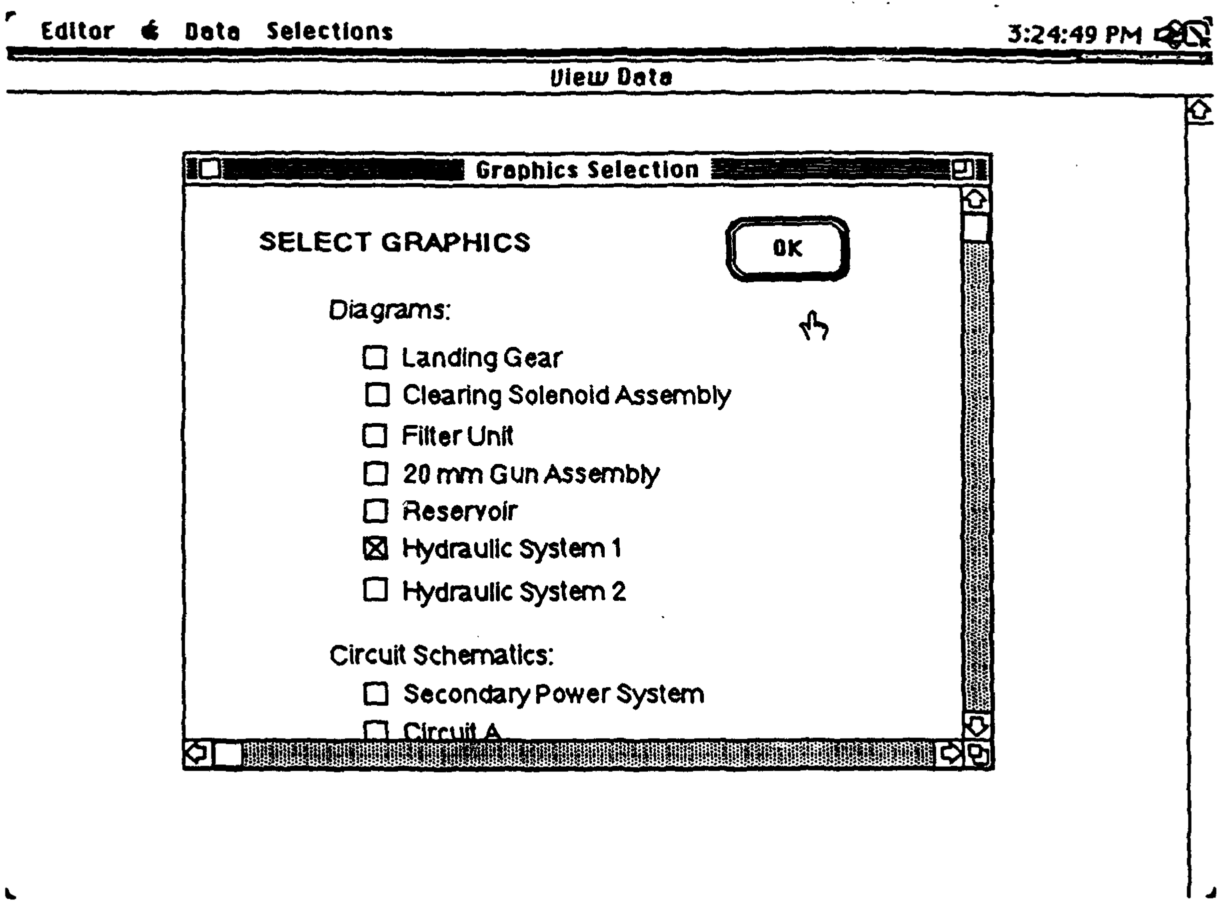

Figure 13. Consequence of User's Selection of Menu Item Graphic (data menu)

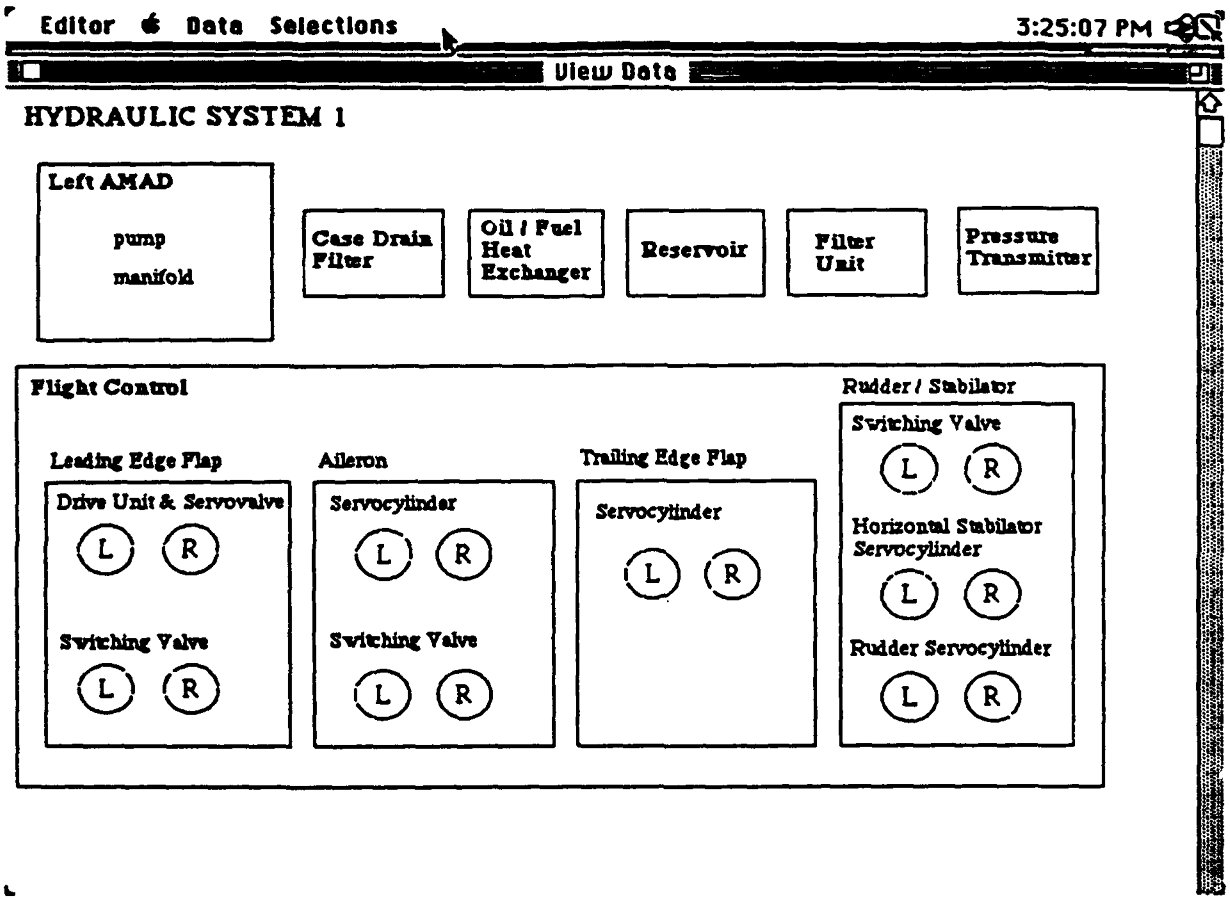

Figure 14. Block Diagram

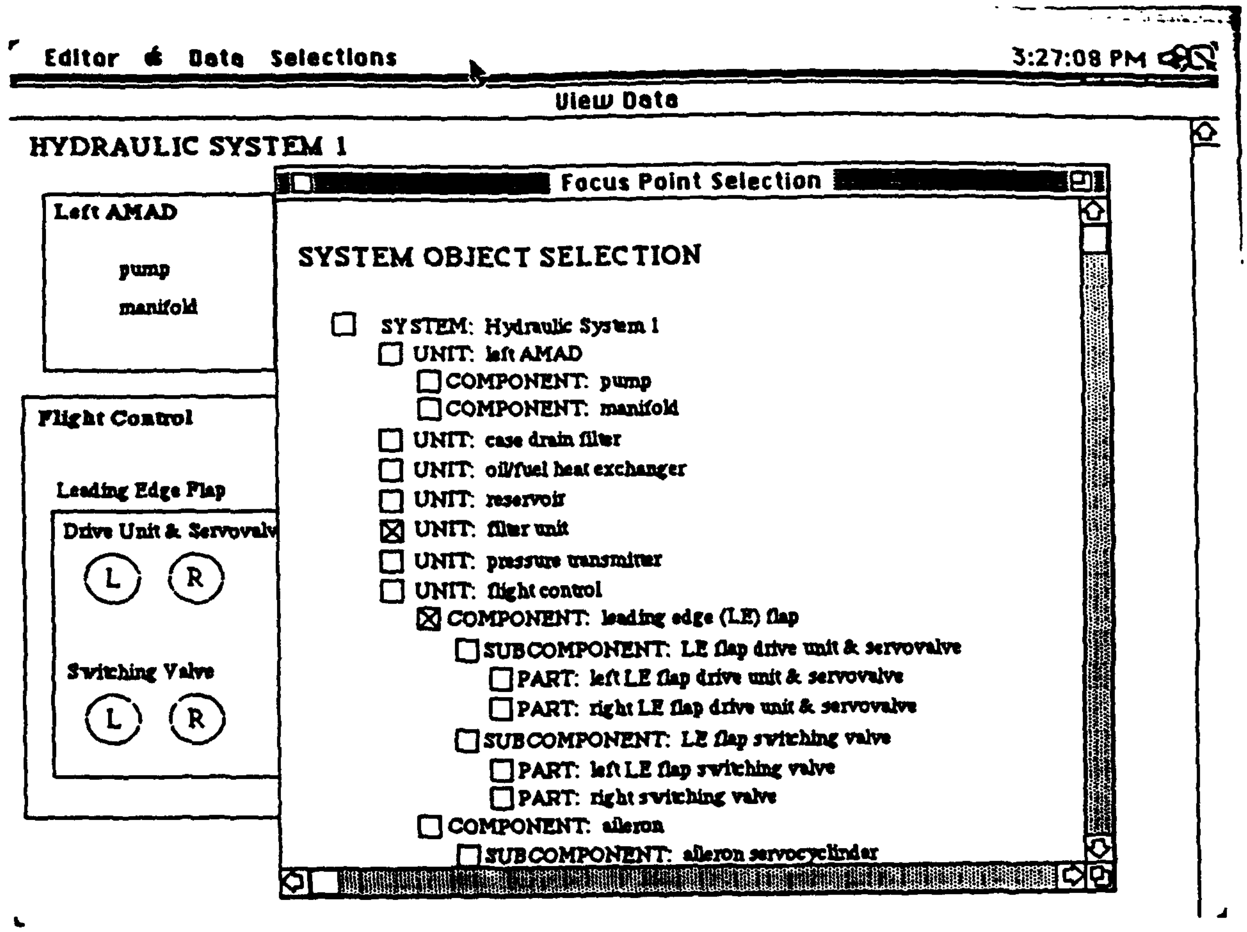

Figure 15. Selection of Focus Points

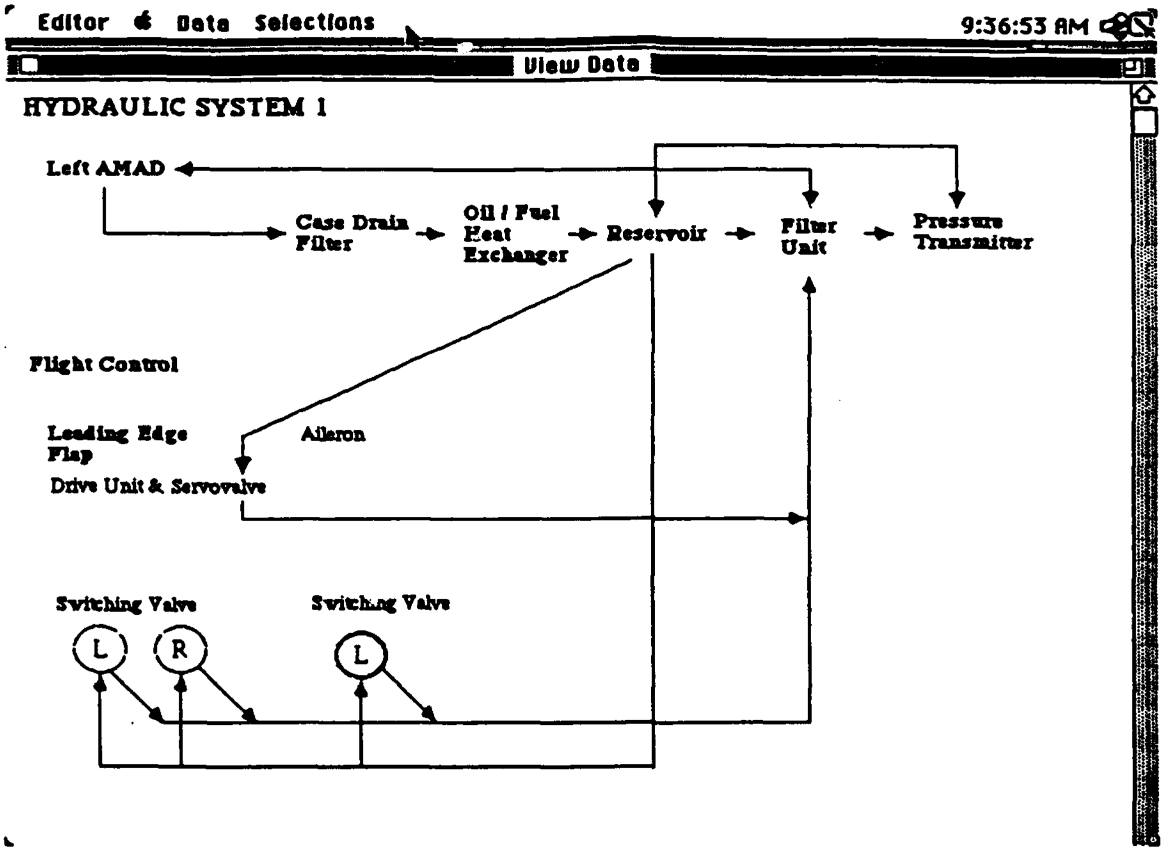

Figure 16. Simplified Graphic

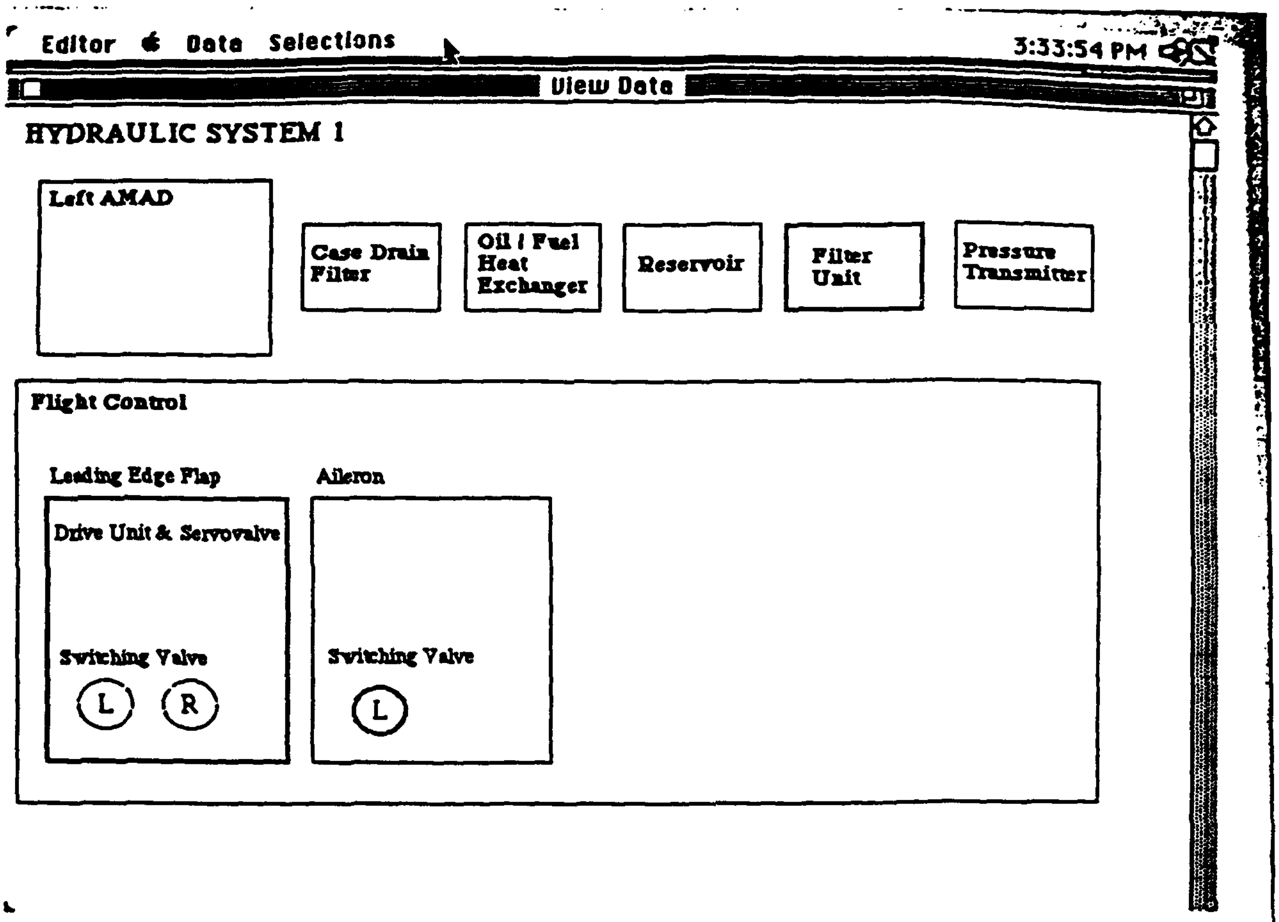

Figure 17. Simplified Graphic

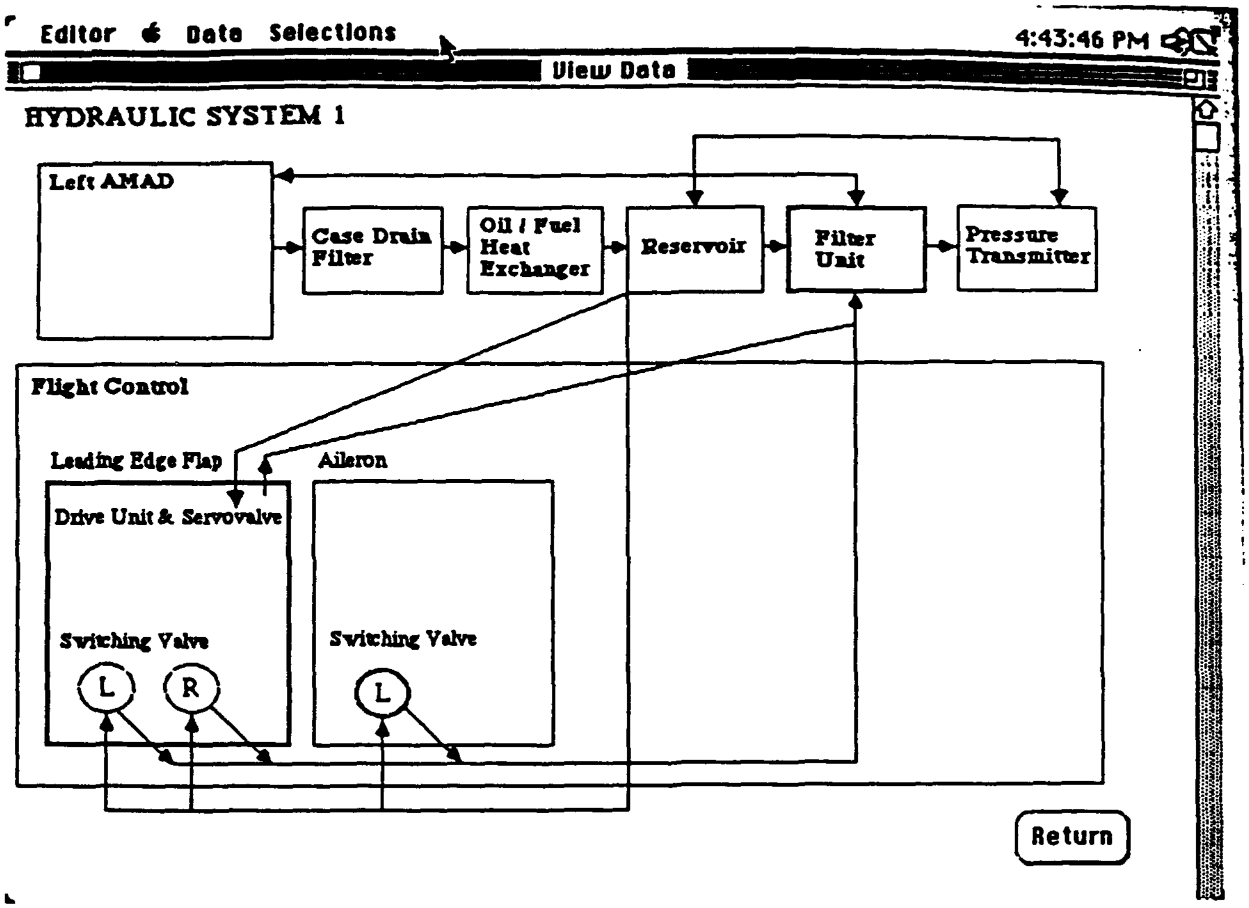

Figure 18. Simplified Graphic

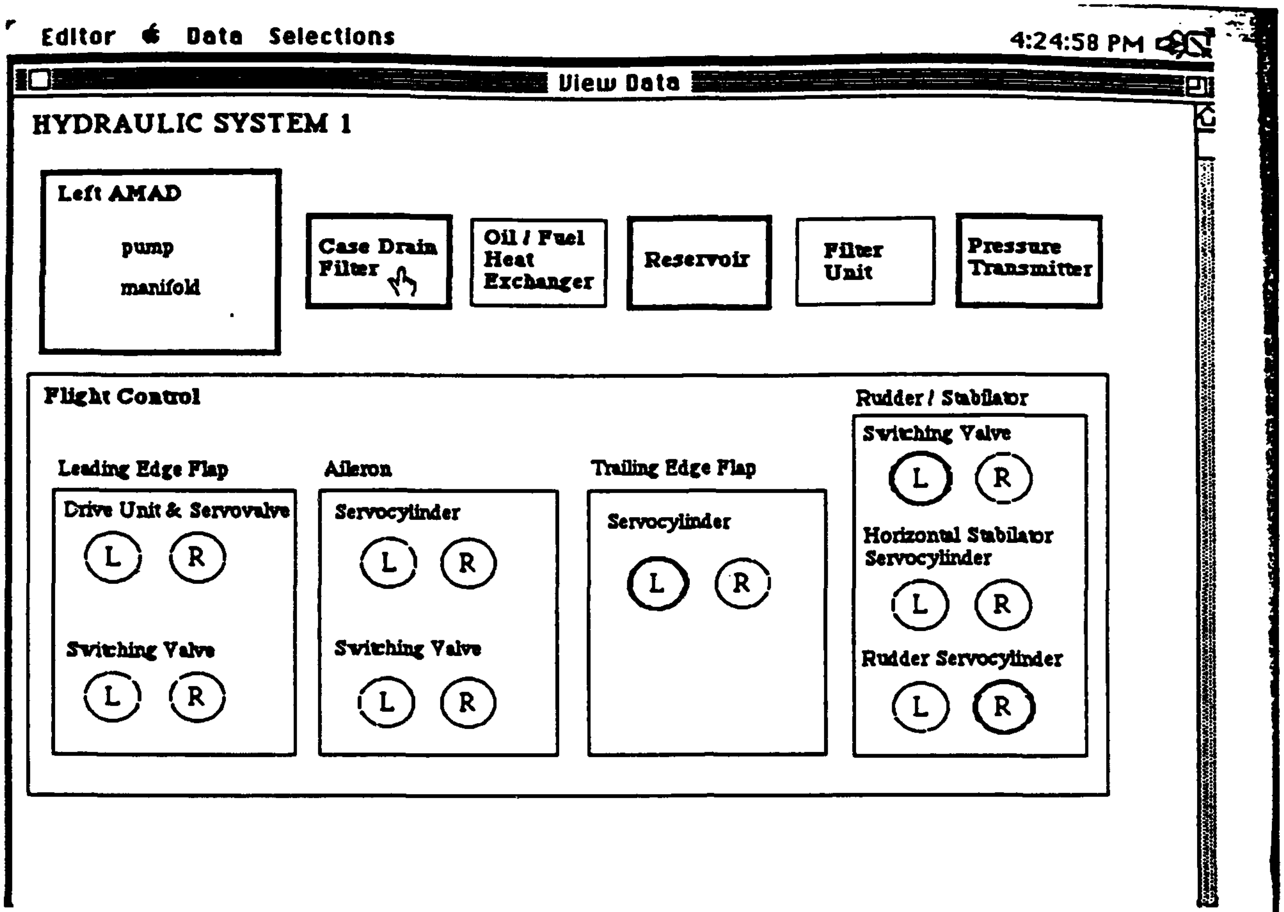

Figure 19. Direct Selection of Focus Points

pressure transmitter, left trailing edge flap servocylinder, left rudder/stabilator switching valve, and right rudder servocylinder. Note that once a particular system object is selected as a focus point, the object is highlighted (Figure 19). In this prototype system, users select objects by clicking on them with a mouse. To deselect a focus point, the user is required to click on the object a second time, whereupon the highlighting is no longer displayed. Also note that the **Selections** menu no longer requires menu item *Focus Points*.

As a second example, suppose a user wishes to view a simplified graphic of Hydraulic System 1, where the simplification is based upon selection of three focus points (left AMAD, reservoir, and left trailing edge flap servocylinder) and subsequent selection of relationship types. Figure 20 depicts the result of the focus point selection process, where all three focus point objects are highlighted. Figures 21, 22, and 23 demonstrate the simplified graphic resulting from selection of menu items *System/Subsystem*, *Input/Output*, and *System/Subsystem & Input/Output*, respectively.

A detailed specification of Hydraulic System 1 (the identification of 38 nodes, or system objects, and two types of relationships that exist between these nodes, S/S and I/O relationships) has defined the network structure underlying this particular F/A-18 aircraft system. The S/S relationship specification defines a five-level network hierarchy consisting of a top level root node (level five). System units are contained at level four, and components are contained at level three. Subcomponents and parts are assigned to levels two and one, respectively. I/O relationships define the following types of connectivities between Hydraulic System 1 objects: unit/unit, unit/subcomponent, subcomponent/unit, unit/part, part/unit, and part/part. Note that inherent to this specification is the implication of directed arcs.

VI. Conclusions and Future Research Considerations

A number of lessons have been learned as a result of this research effort. Specifically, the electronic presentation of maintenance data is a reality. Simplification of complex graphics-based data is an interface design issue that must be addressed; this research demonstrates that the fisheye lens viewing strategy represents a feasible technique for simplifying graphics data. However, in order to determine the actual effectiveness of the fisheye strategy as a means of simplifying graphics-based aircraft maintenance data, human performance data must be acquired. The results of this research suggest that the Aerospace Industries Association's simplified graphics initiative can be implemented analytically via the fisheye strategy. However, the critical task associated with

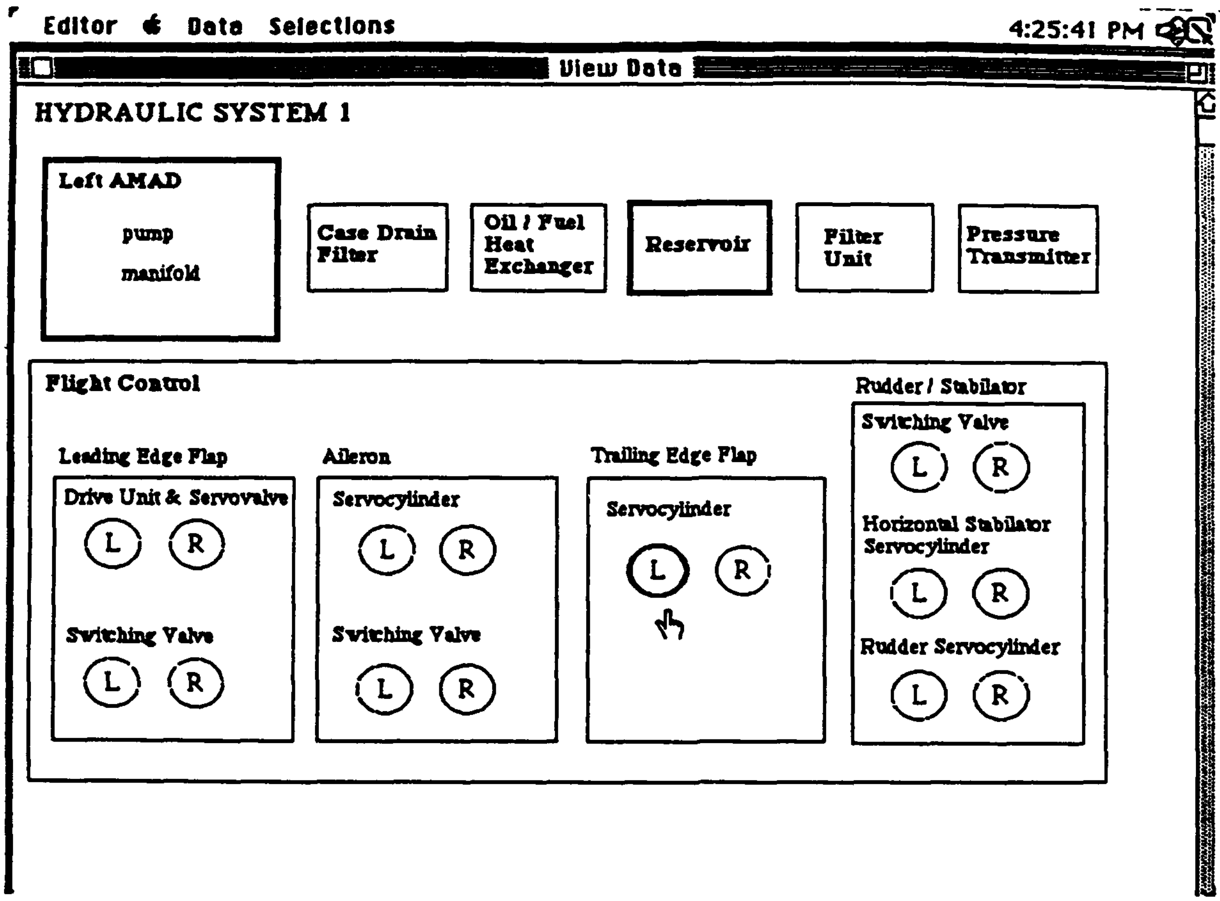

Figure 20. Selection of Focus Points

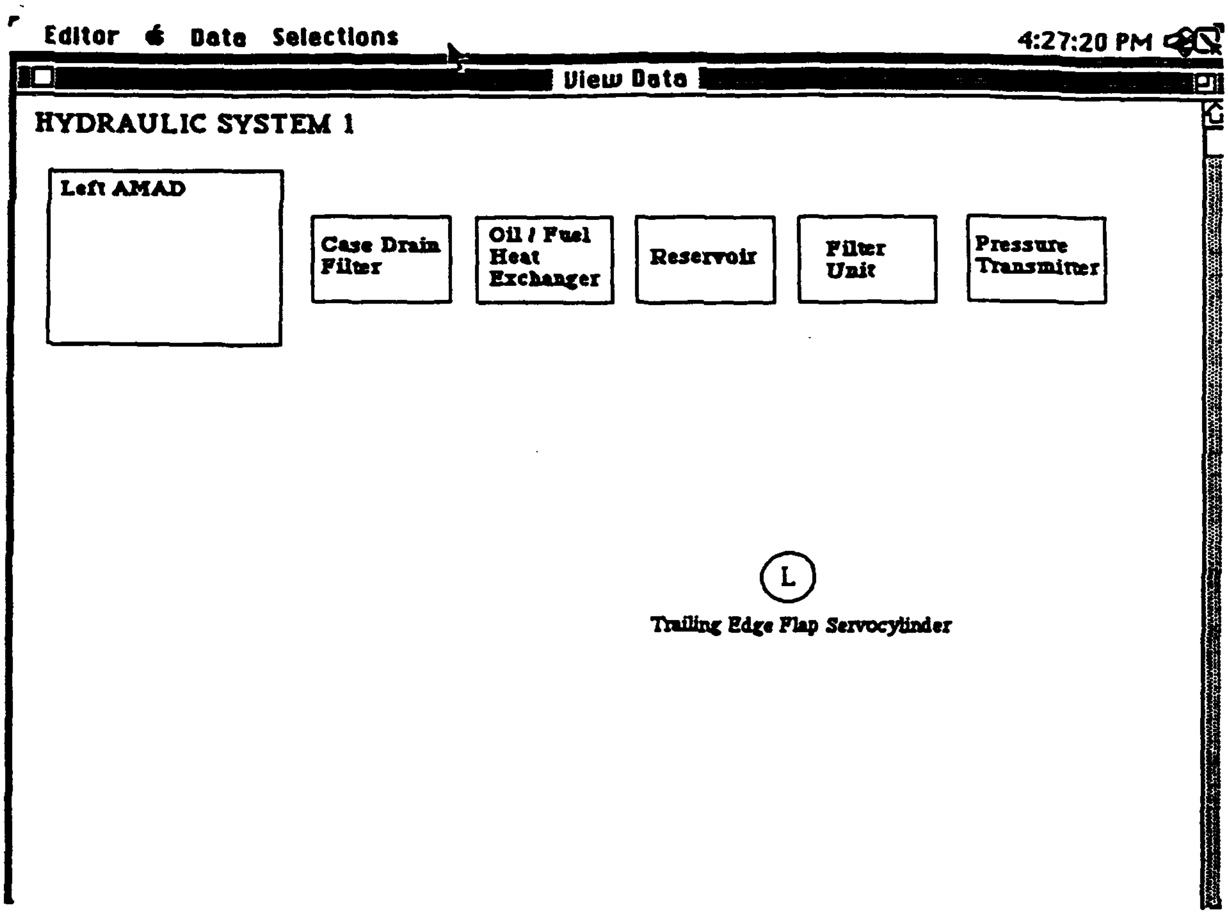

Figure 21. Simplified Graphic

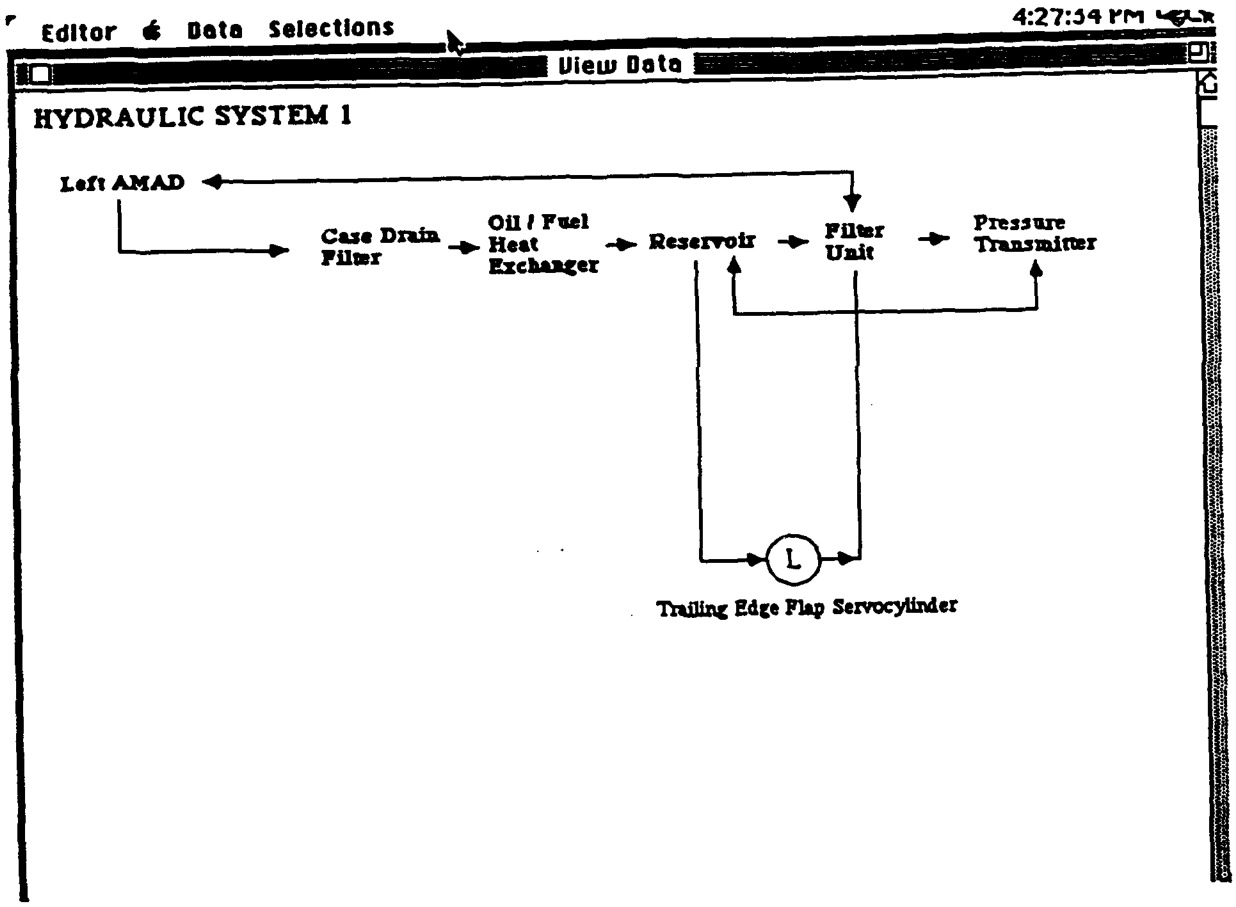

Figure 22. Simplified Graphic

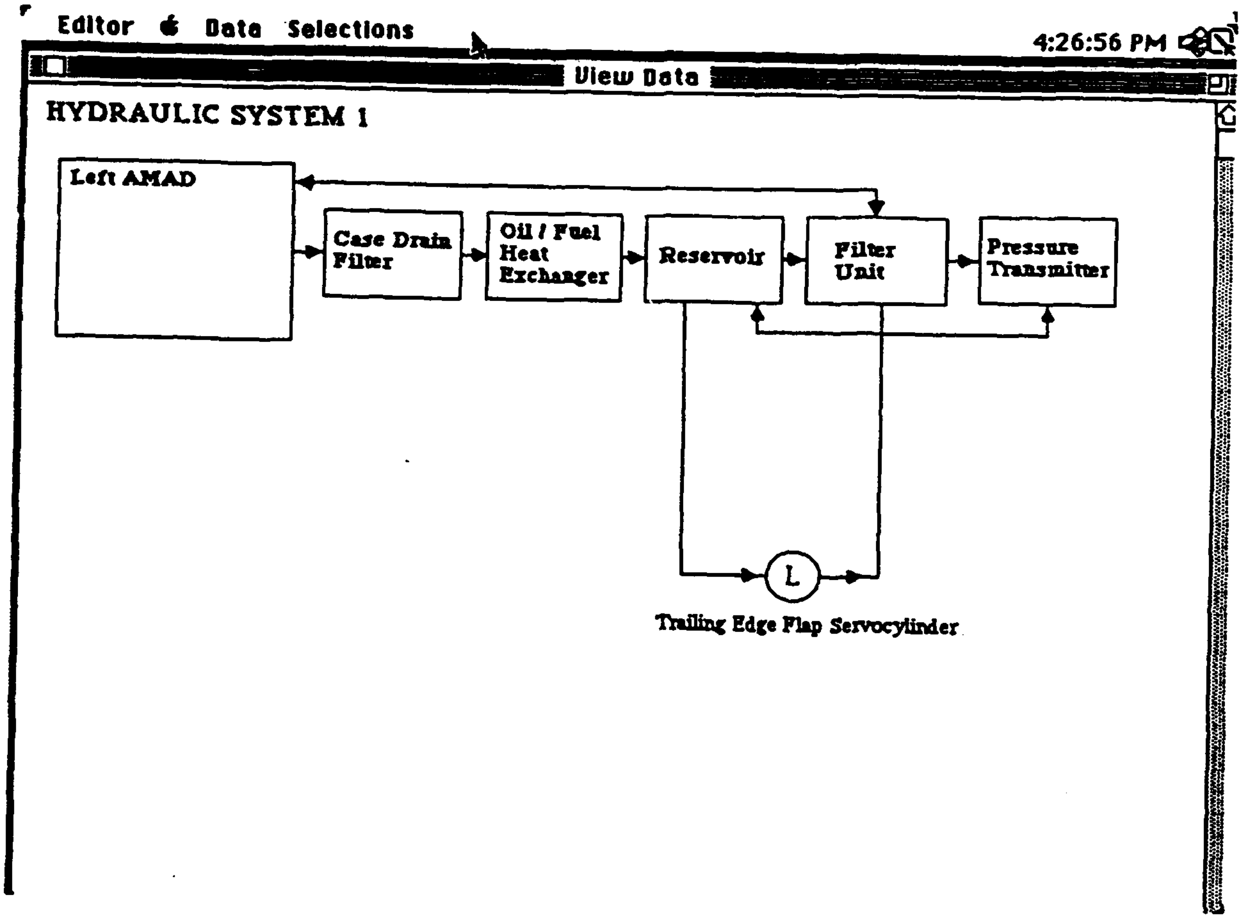

Figure 23. Simplified Graphic

future implementation of the fisheye lens viewing strategy is the authoring of maintenance data such that (1) system objects and (2) the relationships existing between these objects are properly specified.

Several suggestions for future research are offered. While, the fisheye lens viewing strategy is a feasible technique for analytically implementing simplified graphics, Armstrong Laboratory has acquired no human performance data to either support or discourage its future incorporation into the IMIS user interface. At this stage of the research, the effectiveness of fisheye views in enhancing the quality of human-IMIS interaction is undetermined. No empirical research has been performed to examine the extent to which fisheye views enhance a technician's ability to interpret aircraft maintenance graphics. A suggestion for future research, therefore, is to perform a series of pilot studies in which human performance data is used to measure the effectiveness of the fisheye strategy. Acquisition of human performance data is critical to a thorough understanding of how a fisheye interface might be implemented in IMIS.

At this point the data authoring task has required identification and specification of system/subsystem and input/output relationships. A second suggestion for future research is to include the presentation of reliability data (failure probabilities) into fisheye views. A final suggestion for future research is to examine the fisheye strategy as a means of simplifying electronic presentations of text-based data, including maintenance procedures and instructions.

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